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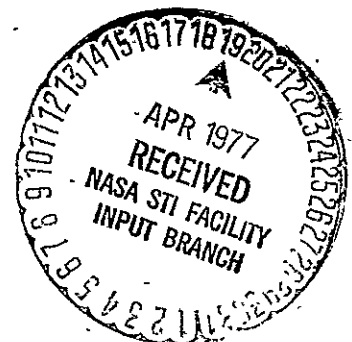
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16 Abstract This report documents the TDRSS operations control analysis study conducted during February - November 1976. This study was performed in three phases. Phases I and II of this operations control analysis were conducted concurrently with, but independently of, a similar study being performed by NASA personnel. The results of this independent operations control analysis study are contained in the body and all but the final appendix of this report. This analysis was based upon the use of an operational Tracking and Data Relay Satellite System (TDRSS) and the remaining Ground stations for the STDN (GSTDN). Phase I of the study compared the operational aspects of TDRSS Concepts I and II, GSTDN as a 14-site network, and GSTDN as a 7-site network, with operating loads as described by the TDRSS Planning Mission Model, July 1975, revised to include GSTDN. The result of Phase I was a principal, and set of alternative, operations control concepts for the above configurations. Phase II developed the principal and alternate control concepts derived in Phase I into methodologies, overall guidelines, characteristic descriptions, and costs of the TDRSS/GSTDN Operations Control System. In addition,			
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16. Abstract (continued)

attention was directed toward the methodology and guidelines in two specific areas of concern, the man/machine interface and scheduling system. As a component of a human factors analysis, a bibliography and referral matrix was developed and is contained in Appendix G, Specialized Human Factors Primer. This bibliography and referral matrix identify salient studies and references dealing with the primer subject matter and additional sources of human factors expertise in these areas. At the completion of Phase II, the desired attributes of the TDRSS era Network Control Center (NCC) were defined by NASA. Phase III focused on selected NCC issues which included hardware/software tradeoff analyses, feasibility studies and detailed system descriptions for critical aspects of the operations control system.

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EXECUTIVE SUMMARY

Executive Summary

OVERVIEW OF THE TDRSS OPERATIONS CONTROL ANALYSIS STUDY

This three phase effort performed an operations control analysis study of the Spaceflight Tracking and Data Network (STDN) for the TDRSS era.

Background

This report documents the Tracking and Data Relay Satellite System (TDRSS) operations control analysis study conducted during February - November 1976. This study was performed in three phases. Phases I and II of this operations control analysis were conducted concurrently with, but independently of, a similar study being performed by NASA personnel. At the conclusion of the independent analysis NASA identified the desired attributes of the TDRSS era operations control system. Phase III of this study focused on specific control system issues identified by NASA. Analysis of these issues were then conducted in conjunction with related NASA efforts. The results of the independent operations control analysis study (Phase I and II) are contained in the basic text and are supported by eight of the nine appendices. The last appendix contains the results of Phase III analyses. The Phase I and II analyses were based upon the use of an operational TDRSS and a maximum of seven Ground STDN (GSTDN) tracking stations. Phase I of the study compared the operational aspects of TDRSS Concepts I and II, GSTDN as a 14-site network, and GSTDN as a 7-site network, with operating loads as described by the TDRSS Planning Mission Model, July 1975, revised to include GSTDN. The result of Phase I was a principal, and set of alternative operations control concepts for the above configurations. The methodologies and costs for implementing these control concepts were subsequently developed in Phase II.

Phase I Scope and Objectives

Phase I studied the plans for the TDRSS/GSTDN era of operations to determine the nature of the operations control requirements and developed the appropriate principal and alternate operations control concepts. The objectives of the Phase I analysis were to select a Principal Control Concept for the orderly functioning of the TDRSS era STDN and to examine the effects on this control concept of varying mission loading, the number of GSTDN sites, and the TDRSS configuration (Concept I versus Concept II).

Phase II Scope and Objectives

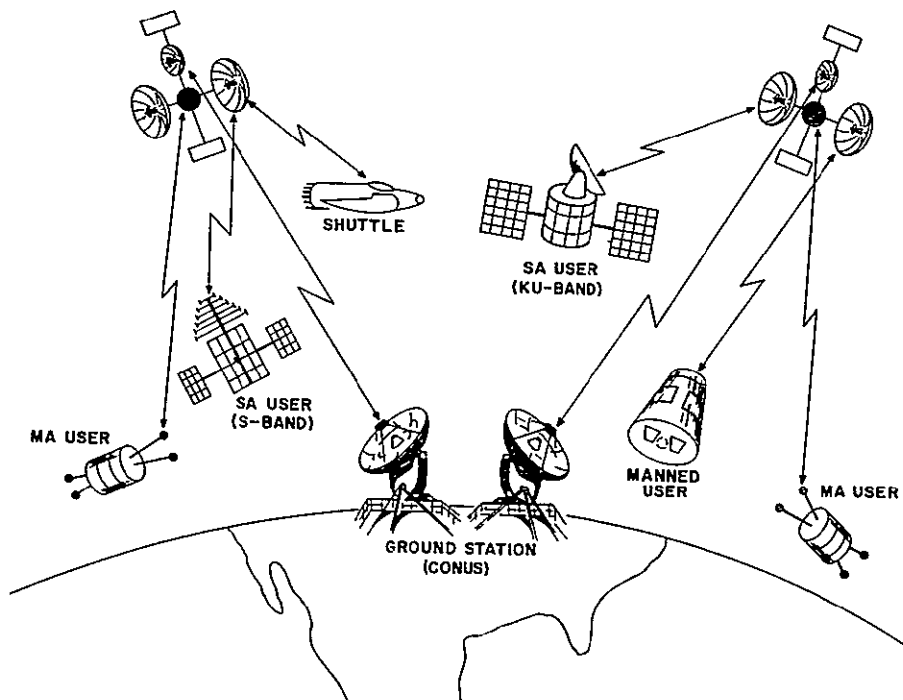
The principal and alternate control concepts derived in Phase I were developed into methodologies, overall guidelines, characteristic descriptions, and costs of the TDRSS/GSTDN Operations Control System. In Phase II, particular attention was also directed toward the methodology and guidelines in two specific areas of concern, the man/machine interface and scheduling system. The first of two Phase II objectives was to identify the impacts

on operations seen for the alternate control concepts defined in Phase I. The second objective was to define an efficient relationship between manual skills and machine capabilities for use in Network Operations Control Center (NOCC) interactions with the Payload Operations Control Center (POCC) and network elements.

Phase III Scope and Objectives

Phase III analyses focused on special operations control system issues identified by NASA. The overall objectives of this phase were to support Network Control Center (NCC, renamed from the current NOCC) Automatic Data Processing (ADP) Feasibility Study. Additional analyses were conducted in support of the overall definition of NCC operations in the TDRSS era.

TDRSS TWO-SATELLITE SYSTEM CONCEPT



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FINDINGS OF THE PHASE I ANALYSIS

Within the context of plans for the TVRSS/GSTDN era of operations, Phase I determined the nature of the operations control requirements and developed appropriate principal and alternate operations control concepts. A sensitivity analysis was conducted to determine the impact of loading and TVRSS/GSTDN configuration variations on the Principal Control Concept.

Hardware/Software Systems

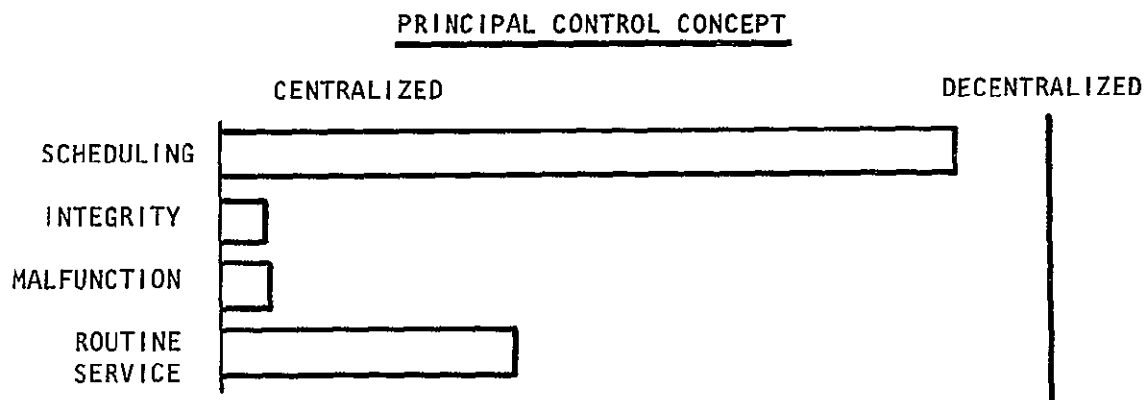
In developing the control methodologies, two new software/hardware automated routines were specified to increase the efficiency of the network operations, permit the decentralization of work and responsibility when desired, and allocate routine processing to machines and decision making to people. The Automated Scheduling Routine (ASR) is designed to permit both long lead time scheduling and real-time scheduling. If so configured by the Network Operations Control Center (NOCC), users could enter their requests for service directly into the ASR and have rapid knowledge of scheduling of the event, conflicts that exist, and possible alternative scheduling times. The Control and Status Monitoring System (CASMS) automates many of the NOCC interfaces with STDN users and permits routine service to be decentralized to the degree desired by the NOCC

Control Concept Development/Selection

Phase I approached the development of a Principal Control Concept by segmenting the Network operations into four independent task areas: scheduling; system integrity; malfunction identification, isolation and restoration; and routine service. For each area, alternative control methodologies were defined and an analysis applied to select the preferred methodology. The Principal Control Concept was then formed by combining the preferred methodologies.

In developing the alternatives, three generic control concepts were defined: centralized control; decentralized control; and matrix control. While the centralized and decentralized control concepts vested the work, responsibility, and authority in the NOCC and the users respectively, the matrix control concept vested the authority in the NOCC and gave the NOCC the ability to delegate the work and the responsibility between the NOCC and the users. This concept gave the NOCC extreme flexibility and efficiency in providing maximum service to the users while at the same time standardizing user interfaces. The resulting Principal Control Concept is one that uses the matrix control concept for the task areas of scheduling and routine service and the centralized control concept for the tasks of system integrity and malfunction identification, isolation and restoration.

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- PERMITS THE NOCC TO DECENTRALIZE THE WORKLOAD WHILE RETAINING STDN OPERATIONAL AUTHORITY
- ALLOCATES NETWORK AND SPACECRAFT RESPONSIBILITY TO THE NOCC AND POCC, RESPECTIVELY
- ALLOWS THE NETWORK TO BE HIGHLY TRANSPARENT TO USERS
- PROPERLY DISTRIBUTES NETWORK ACTIVITIES BETWEEN MEN AND MACHINES
- ENSURES UNIFORMITY OF INTERFACE OPERATION THROUGHOUT SPECTRUM OF OPERATIONS

Executive Summary

FINDINGS OF THE PHASE I ANALYSIS

Sensitivity Analysis

The Principal Control Concept was subjected to a sensitivity analysis which considered variations in the TDRSS daily loading, variations in TDRSS configuration, support of the Space Shuttle, variations in GSTDN configuration and variations in the GSTDN loading.

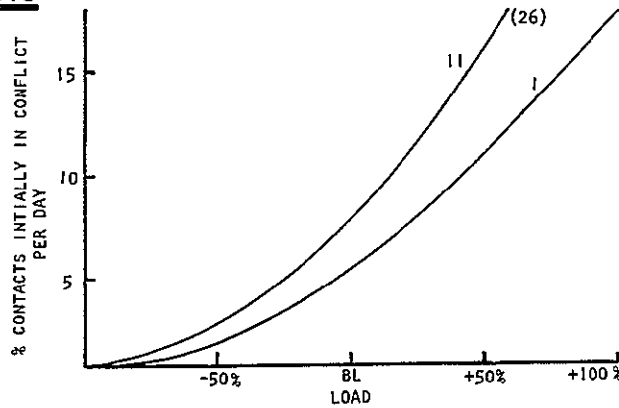
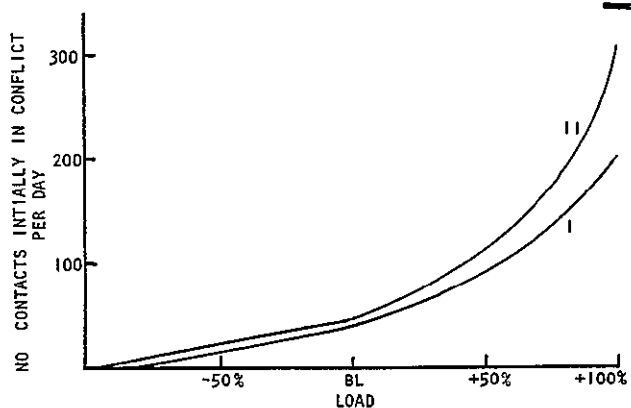
An examination was made of varying both the loading and the configuration of the TDRSS. In both cases, the major impact on the Principal Control Concept was in the operations task of scheduling. As the load increased, the number and the severity of the conflicts increased. The results indicated that a more sophisticated scheduling algorithm would be needed to resolve the conflicts. For all levels of loading, the TDRSS configuration using Single Access service only produced more conflict problems than the TDRSS Configuration using both Multiple Access and Single Access service.

The major impact of adding a Space Shuttle was with the scheduling task. The addition of one Space Shuttle was equivalent to increasing the load by +50%, and the addition of two Space Shuttles was equivalent to increasing the load by +75% to +100%. Both the number and severity of the conflicts increased in each case.

When the number of GSTDN sites was increased from the baseline seven to the current fourteen, additional service and back-up service for the Shuttle could be provided. When the number of sites was reduced to less than seven, two impacts were noticed. First, scheduling was once again affected. Second, the average service that could be provided to the GSTDN users was decreased and continuous dedicated support was seen to suffer numerous interruptions.

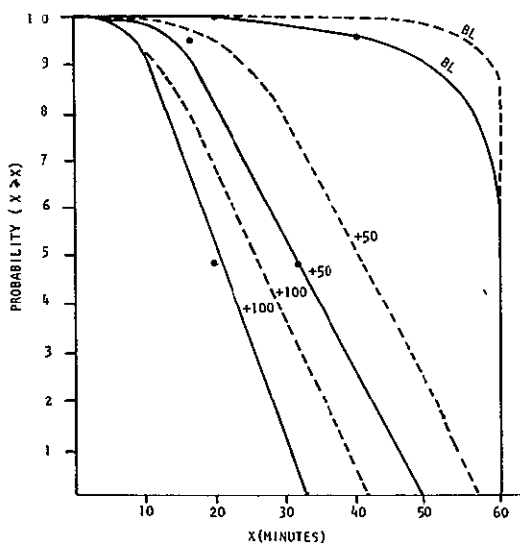
SENSITIVITY ANALYSIS

CONFLICTS

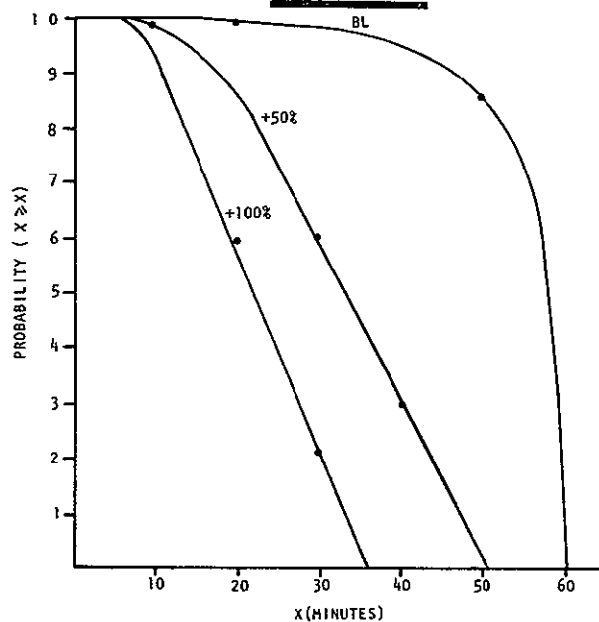


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CONCEPT II



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FINDINGS OF THE PHASE II ANALYSIS

The key findings of the Phase II analysis can be related directly to: Control Concept Refinement; Automatic Scheduling Routine; Control and Status Monitoring System; STDN Operations Center Staffing; Human Factors and Costing.

Control Concept Refinement

The Phase II analysis refined the operations control concepts developed in Phase I. The results of this refinement are identified below.

- The Principal Control Concept identified in Phase I is a viable and cost competitive alternative.
- The estimated life-cycle cost for the control system is 19 million dollars using inflated 1976 dollars.
- Use of a refurbished NOCC saves 900 thousand to one million dollars over constructing and equipping a new facility.

Automatic Scheduling Routine

During Phase II, ASR implementation and algorithm requirements were developed. The results of this analysis are as follows:

- The ASR can be justified on projected workload and manpower savings over a totally manual system. This savings amounts to 5 million dollars over the 1978-1990 period.
- Dedicated hardware should be used for the ASR.
- Combined ASR hardware and software costs are estimated at 500 to 800 thousand dollars using 1976 dollars.
- A sophisticated algorithm is required for the ASR. It initially utilizes a multiple-pass feasibility search while maintaining a capability for the addition of heuristic loading rules.
- Network Operations Management must specify the objective functions to be used by the ASR algorithm.
- Existing algorithms are likely to satisfy a portion of the ASR requirements. However, it is unlikely that any existing algorithm will be directly applicable to the entire STDN problem. N/2 Job Shop and Branch and Bound algorithms appear to be the most useful techniques for satisfying STDN requirements.

Control And Status Monitoring Systems

Characteristics of CASMS were defined to allow hardware and software development costs to be estimated.

- Information requirements can be met by five message categories with messages of under 100 bits in length
- Processing requirements were found to be well within the capability of current mini-computers.
- Hardware and software development costs were estimated to be between 400 and 700 thousand dollars in 1976 year dollars

STDN Operations Center Staffing

The concepts and guidelines necessary for the determination of the STDN control center staff were developed during this analysis effort. The impacts of loading and control concept variation upon operations center personnel requirements were also assessed.

- Between seven and eight console positions are required in the operations center. The requirement to staff these positions continually translates into a need for 30 to 40 people
- Ten to fifteen support positions for the Operations Center were identified. Manpower estimates were developed based on staffing these positions for a normal 40-hour work week, 50 weeks a year. As a result, 10 to 15 support personnel requirements were identified.
- Almost ninety percent of the life-cycle cost for the Operations Control Concept is in manpower. For the Operations Center and support personnel identified above, this cost is approximately 17 million dollars in inflated 1976 dollars.
- A 100 percent increase in the STDN load resulted in the requirement for additional positions in the Operations Area. The associated life-cycle cost impact is an increase of 4.8 million dollars above that of the Principal Control Concept at baseline load.
- A 50 percent decrease in load resulted in a reduction of positions in the Operations Area to 4 or 5. The associated cost impact is a reduction of 1.4 million dollars below that of the Principal Control Concept at baseline load.

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FINDINGS OF THE PHASE II ANALYSIS

- Changing routine service to decentralized control--as opposed to matrix control specified in the Principal Central Concept--provides the least cost alternative for the Operations Control Concept. This results in savings of 1.4 million dollars in terms of inflated 1976 dollars over the Principal Control Concept cost of 19 million dollars. It should be realized, however, that additional Payload Operations Control Center (POCC) personnel would likely be required but have not been costed.
- All remaining control system alternatives required resources in addition to those identified for the Principal Control Concept and hence resulted in higher costs.

Human Factors

Human Factors analysis addressed specific problem areas dealing with the man/machine interface, working conditions and morale.

- The NOCC man/machine interface must not be complex.
- Formal training and personnel selection programs could impact favorably upon the NOCC working environment.
- No requirement was found for color CRT displays.

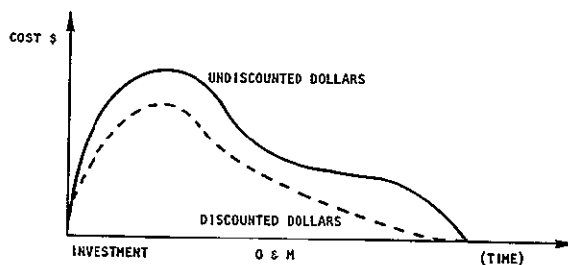
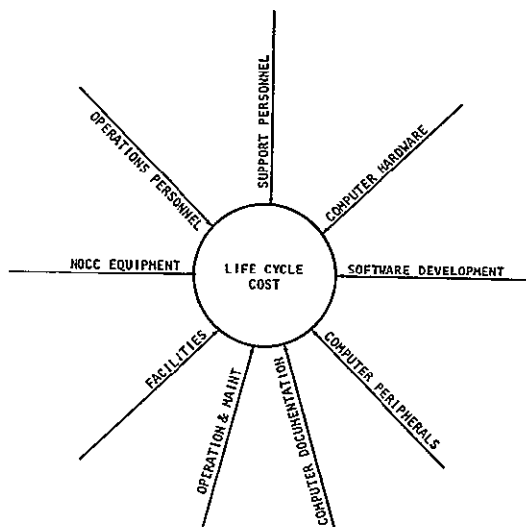
Cost Analysis

The significant factors bearing on the cost analysis and associated results presented above include the following:

- The cost analysis was based on the assumption that quality of service was constant.
- The control concept alternatives were compared on the basis of 1976 dollars, inflated dollars, and discounted dollars. Discounting inflated dollars was used as a method by which both negative and positive effects of time can be accurately accounted for in a given period.
- Implementation decisions made on the basis of discounted dollars are consistent with decisions that would occur if the analysis was based on inflated dollars. This results from the stable cash flow over the period of time considered.

The factors influencing the life cycle cost, the effect of discounting dollars and the results of the life cycle costing for the Principal Control Concept are shown in the figure.

LIFE CYCLE COSTING AND THE EFFECT OF DISCOUNTING



PRINCIPAL CONTROL CONCEPT: LIFE CYCLE COSTING

	FY	77	78	79	80	81	82	83	84	85	86	87	88	89	90	T	IT	OT
FACILITY			125	125												25		
INFLATED (6%)			14	15													29	
DISCOUNTED (10%)			12	11														23
HARDWARE			28													28		
INFLATED			31														31	
DISCOUNTED			26															26
SOFTWARE DEV		4	4													8		
INFLATED		424	449														873	
DISCOUNTED		385	371															756
NOCC EQUIPMENT		1														1		
INFLATED		11															11	
DISCOUNTED		09																09
PERSONNEL					9	9	9	9	9	9	9	9	9	9	9	9	16	96
INFLATED					1 14	1 2	1 28	1 35	1 43	1 52	1 61	1 7	1 8	1 9	2 03			
DISCOUNTED					77	76	72	69	67	64	62	59	57	55	53			7 11
O & M					028	028	028	028	028	028	028	028	028	028	028	308		
INFLATED					035	037	04	042	044	047	05	053	056	059	063		526	
DISCOUNTED					024	023	023	022	021	02	019	019	018	017	017			223
																11 64 19 0	8 7	

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SUMMARY OF PHASE III ANALYSES

Phase III analyses focused on special operations control system issues identified by NASA. Support was provided to the development of NASA's NCC Automatic Data Processing (ADP) Feasibility Study with additional analyses conducted in support of the overall definition of NCC operations in the TDRSS era.

General

As previously indicated, Phase III analyses focused on critical operations control system issues as selected by NASA. Since these analyses are independent of the Phase I and II study, the results and conclusions for Phase III have been incorporated in Appendix I. The major areas considered were NCC Requirements and Definition, Manpower Cost Estimates, Software Specifications, Message Sizing and Data Rate Requirements, and NCC Controller Manpower Requirements.

NCC Requirements and Definition

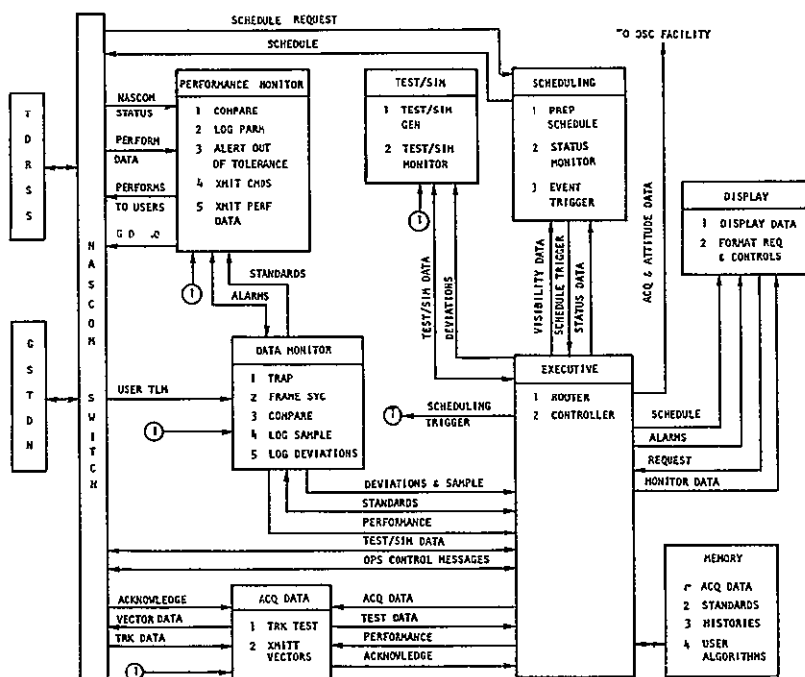
The NCC Composite Functional Flow Diagram shown in the figure served as the basis for the ADP requirements and definitions identified during Phase III. For each of the functions identified, with the exception of "Display," "Memory," and "Data Monitor" functional descriptions, processing requirements, detailing subfunction task and element requirements; input/output message sizing and rates, and storage requirements were developed. Subsequently a computer configuration and software cost analysis was performed. Hardware computer costs were developed for the NCC ADP equipment arranged in a Star, Ring or single "medium" size configuration. Based on the cost estimates provided in Appendix I, the medium size computer configuration for the NCC seemed the most desirable. The hardware/software cost for this configuration was estimated to be \$1,086,600. The hardware/software costs for the Star and Ring configurations were estimated to be \$1,771,700 and \$2,074,150 respectively.

Based on the above requirements and definitions, a description of the real time event flow characteristics of the ACQ DATA function was developed. Personnel/machine tasks and responsibilities were discussed in both routine and emergency environments. Included was an identification of information (such as various test and comparison results, alarm messages, etc.) to be displayed on the ACQ DATA CRT for operator review and/or action.

Software Specifications

To demonstrate a form and format for the NCC ADP system software specification, a representative example of the specification for the ACQ DATA function was developed. The format was guided by standard procedures for the presentation of computer software specifications. Major paragraphs presented the overall scope and a short description of major program functions; applicable documents, and detailed requirements placed on the software, including Runge Kutta equations to be used for Inter Range Vector (IRV) integration.

NCC COMPOSITE FUNCTIONAL FLOW DIAGRAM



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Executive Summary

SUMMARY OF PHASE III ANALYSIS

Manpower Cost Estimates

Based on NCC staffing estimates developed by NASA, 10 year cost comparisons were made between projected NCC staffing and current NOCC staffing. Yearly manpower costs were provided for the years 1980 and 1990. These estimates were provided for low (L), midrange (M), and high (H) salary categories. As can be seen in the table, the future NCC staffing was projected to save from 16.7 to 23.2 million dollars over the 10 year period when inflation is considered.

NCC Controller Manpower Requirements

Through an extension of the analysis conducted in the Phase II Manpower study, the load dependent manpower required in support of both TDRSS and GSTDN was developed. A more realistic simulation of expected event arrival rates was obtained, along with an individual assessment of TDRSS MA and SA activity under various load conditions and network setup/teardown times, and GSTDN manpower requirements in a peak load environment. It was found that to insure the real time consideration of all simultaneous events for the baseline 1980s TDRSS system load, two MA and two SA controllers are required. At twice baseline load, three MA and four SA controllers would be needed. In addition, it was found that three GSTDN operators are sufficient to absorb the heaviest expected workload in the early 1980s. The description of simultaneous event characteristics such as average per minute, maximum per load, and frequency which were used to derive the manpower requirements is also given. The table opposite exemplifies these results.

The statistics in the table are given parametrically for various values of T, the time required for an SA, MA, or GSTDN controller to carry out the necessary set of events for network assembly and disassembly. The simulation which provided these statistics considered realistic satellite contact initiation and duration timing. However, during one satellite's actual contact period, it was assumed that the controller's time was essentially free to perform alternate setup and teardown events, i.e., only setup and teardown were considered "operator events." For baseline loading conditions the table lists the maximum number of (simultaneous) events, and the number of operators required to perform such tasks. The assumption was made that an operator can perform three events simultaneously, thus six simultaneous events requires two operators (No. Req. Operators). Other statistics generated were Operator Free Time -- the percentage of time that an operator (1, 2, or 3) would be "idle," and Most Frequent (Number of) Events -- the number of simultaneous events which occurred most frequently, and the percentage of time in which that number occurred. In computing operator free time, it was assumed that each successive controller accepted only those events exceeding his predecessor's saturation level.

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MANPOWER COST COMPARISON

		NCC									CURRENT STAFF								
TYPE \$ YR CAT		76T			IT			DT			76T			IT			DT		
		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
80		21	25	29	26	31	36	18	21	25	30	36	41	37	44	51	26	30	38
81		21	25	29	28	33	38	17	20	24	30	36	41	40	47	54	24	29	34
82		21	25	29	29	35	41	16	20	23	30	36	41	41	50	59	23	29	33
83		21	25	29	31	37	43	16	19	22	30	31	41	44	53	61	23	27	31
84		21	25	29	33	39	46	15	18	21	30	36	41	47	56	66	21	26	30
85		21	25	29	35	42	49	15	18	21	30	36	41	50	60	70	21	26	30
86		21	25	29	37	44	51	14	17	20	30	36	41	53	63	73	20	24	29
87		21	25	29	39	47	54	14	16	19	30	36	41	56	67	77	20	23	27
88		21	25	29	42	50	58	13	16	18	30	36	41	60	71	83	19	23	26
89		21	25	29	44	53	61	13	15	18	30	36	41	63	76	87	19	21	26
90		21	25	29	47	56	65	12	15	17	30	36	41	67	80	93	17	21	24
TOTALS		231			391			163			330			558			233		
			275			467			195			396			667			279	
				319			542			228			451			774			328

* VALUES IN MILLIONS OF DOLLARS

NCC SIMULTANEOUS EVENT CHARACTERISTICS FOR BASELINE LOADING

SERVICE	T (MIN)	MAXIMUM NO EVENTS	NO. REQ. OPERATORS	OPERATOR FREE TIME			MOST FREQUENT EVENT/FREQ.
				1	2	3	
SA	2	5	2	.58	.99		0/.58
	4	5	2	.30	.97		1/.40
	6	6	2	.16	.93		1/.34
	8	6	2	.10	.79		2/.31
MA	2	3	1	.71			0/.71
	4	5	2	.50	.99		0/.50
	6	6	2	.34	.98		1/.39
	8	6	2	.26	.91		1/.33
GSTDN	2	4	2	.39	.99		0/.39
	4	6	2	.15	.90		1/.29
	6	8	3	.05	.71	.99	2/.24
	8	9	3	.01	.56	.95	3/.23

Executive Summary

SUMMARY OF PHASE III ANALYSIS

Message Sizing and Data Rate Requirements

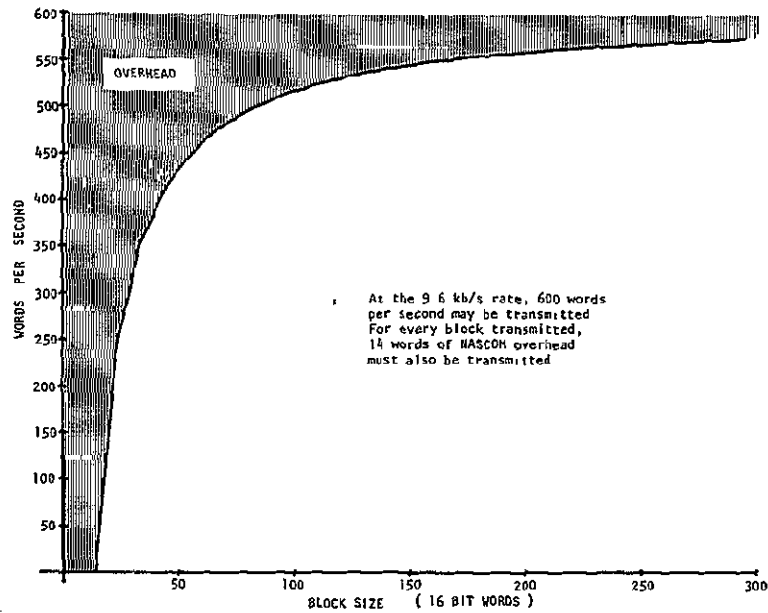
To provide block sizing tradeoffs and evaluate the capability of projected line data rates to satisfy the expected information flow between the NCC and external STDN elements, an analysis of message sizing and data rate requirements was conducted. The messages, and their approximate sizes, which comprise the majority of communications identified to date were used.

At the right are illustrations of the block sizing tradeoff analysis. The upper graph, "The Amount of Information Data Transmitted for Various Block Sizes, at a 9.6 kb/s Rate," illustrates the impact of 14 words of NASCOM overhead on the choice of a standard block size. The shaded area represents the percentage of the available 600 words per second that would be transmitted as overhead. Note that the curve tends to be relatively flat for block lengths in the region of 150 to 300 words, and that present NASCOM standard block size is 300 sixteen bit words (4800 bit block). The message sizing analysis indicated that a weekly STDN schedule would consist of approximately 630 thousand words. The lower illustration portrays the amount of pure transmission time required to transmit such a schedule, exclusive of the time required for any communications protocol. Considering these factors, standard block size for NCC traffic in the neighborhood of 150 words, or 2400 bits, was selected.

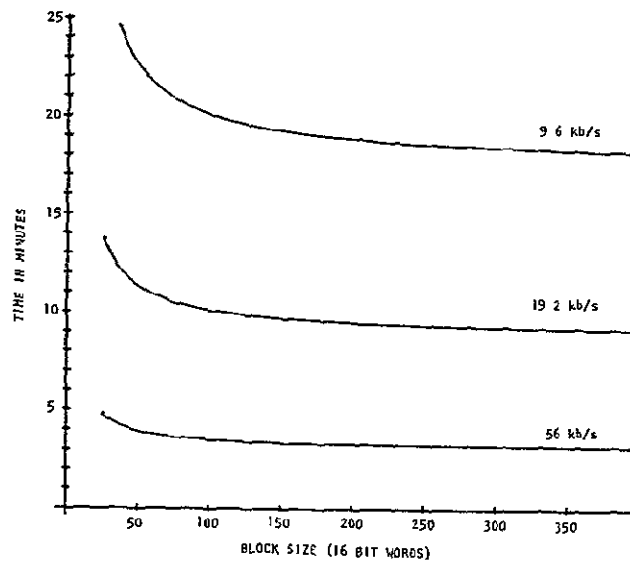
Analysis results indicate that using a 56 kb/s transmission rate on the 1.544 Mb/s NCC-TDRSS link may be very desirable. Since this link will be established, cost incumbrances for an additional 9.6 kb/s line to provide a virtual 19.2 kb/s link, or a 19.2 kb/s channel to replace the 9.6 kb/s line, or a 56 kb/s service to replace the 9.6 kb/s line would not be incurred. These incumbrances could range from \$4,570 to \$9,215 on a monthly recurring basis. Additional benefits include the potential to establish all NCC communications at the 56 kb/s rate.

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THE AMOUNT OF INFORMATION TRANSMITTED FOR VARIOUS BLOCK SIZES, AT A 9.6 kb/s RATE



TIME REQUIRED TO TRANSMIT A 6.3×10^5 WORD WEEKLY SCHEDULE



Executive Summary

STRUCTURE OF FINAL REPORT

The text of this final report documents the results of the Phase I and II analysis efforts. The appendices contain supporting material for these phases as well as documenting the analyses conducted under Phase III.

Phase I Results

The Phase I analysis results are provided in the next section of this report. Following the identification of key assumptions, study context and analysis approach, two major areas are addressed, Principal Control Concept Formulation and Sensitivity Analysis. The analysis approach segmented network operations in four fundamental tasks. Within Principal Control Concept Formulation, each operations task is addressed sequentially and a preferred task control methodology developed. Only the preferred methodology for each task is presented in the body of the report. Details of the alternatives for each operations task are presented in Appendix D. For each operations task, the control methodology is presented by first discussing its characteristics, then the selection rationale and finally, the information flow and interfaces. The Principal Control Concept is then synthesized by combining the preferred task control methodologies.

Within the Sensitivity Analysis, a discussion of the TDRSS variations and impacts upon the Principal Control Concept is presented first. Subsequently, a similar discussion is presented for the GSTDN variations. For both topics, the loading models and key assumptions are presented. Additionally, the potential impact upon results of variations in the assumptions is addressed.

Phase II Results

The results of the Phase II analysis are presented in three major topics; Control Concept Refinement, Human Factors Considerations and Cost Analysis. The refinement of the control concept characteristics described in Phase I is presented in the first topic. The Automatic Scheduling Routine (ASR), Control and Status Monitoring System (CASMS) and Operations Management are addressed. In the refinement of Operations Management, three salient human factors subject areas are addressed: major skill levels needed, task capabilities of the different skill levels, and tool requirements for each skill level. Inclusion of these areas in this section allows the characteristics of Operations Management to be refined to the level where NOCC staffing can be identified and its basis demonstrated in a logical flow.

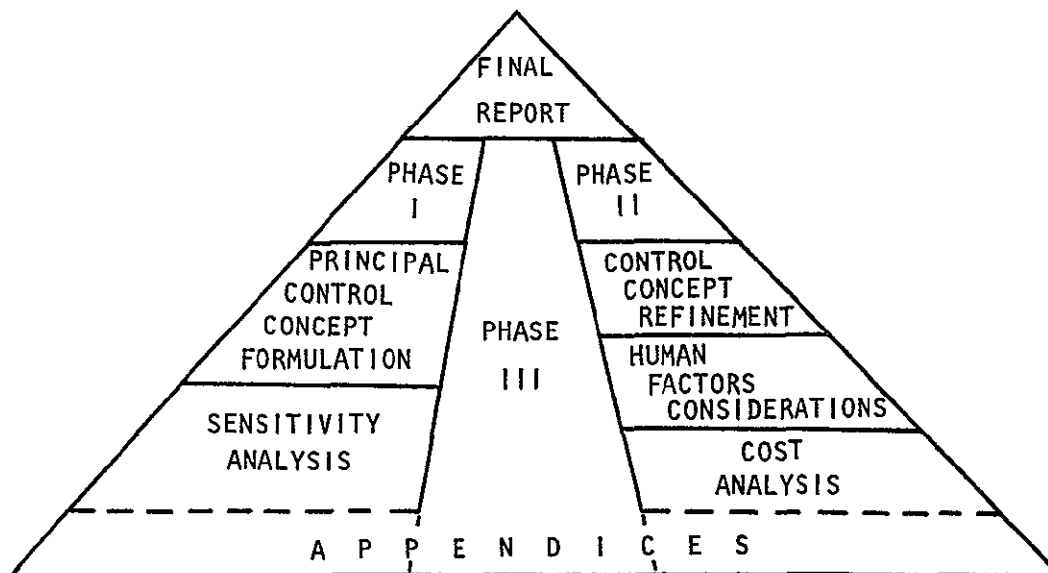
Specifics relating to the STDN Control Center man/machine interface are developed within Human Factors Considerations. Included are working space requirements, CRT display character parameters, personnel selection and training, color versus monochrome display tradeoffs and the man/machine interface. Supplementing the specific areas treated within the body of the report, is a specialized human factors primer which treats the general area of working conditions. This primer (Appendix G) presents guidelines and methodologies for determining and implementing working condition changes motivated by human factors considerations.

For the various control concepts developed in Phase I, and the associated refinements, Rough Order of Magnitude (ROM) cost estimates are provided for major control system components. Cost Summaries are provided in the report and supported with detailed cost data sheets in Appendix H. Cost comparisons are made between the Principal Control Concept and alternatives synthesized in Phase I. This material is presented in the third topic, Cost Analysis.

Phase III Results

As previously indicated, Phase III analyses focused on critical operations control system issues as selected by NASA. Since these analyses are independent of the Phase I and II study, the results and conclusions for Phase III have been incorporated in Appendix I. The major areas considered were NCC Functional Requirements and Definition (Appendix I, Section 1, 2 and 6), Manpower Cost Estimates (Appendix I, Section 3), and Software Specifications (Appendix I, Section 4 and 5).

FINAL REPORT STRUCTURE



**PHASE I
ANALYSIS RESULTS**

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INTRODUCTION

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Introduction

THE TDRSS ERA WILL CREATE MAJOR CHANGES IN STDN OPERATIONS

Current STDN operations are characterized by store and forward data transmission from ground sites, geographical restrictions on duration and availability of support, and "positive reporting." This is in sharp contrast to the TDRSS era which will be characterized by real time data transmission, near continuous viewing of spacecraft, and increased automation of network operations.

Summary Of Current STDN Operations

Present STDN operations exhibit four characteristics. First, store-and-forward methods of transfer of spacecraft data to the user are employed. The large volume of data received daily by the STDN greatly exceeds the constraints placed on its relay from ground site to GSFC by data communications capabilities. This mode of operations tends to decrease user confidence in the quality of his data because no method of real time data quality evaluation is available. Second, the scheduling of Low Earth Orbit (LEO) spacecraft contacts at present is limited by geographical factors as well as mission-unique support requirements that call for the use of stations specially equipped with that mission's support hardware or software. Geography dictates unavoidable restrictions in duration of spacecraft-station contact, as well as in the portion of orbit available for support. Third, mission-unique support requirements compound this problem of geographic constraints. Many sites are uniquely configured, making for non-standard interfaces, as well as removing stations from the total pool of support available because of their "semi-prioritized" configuration. Fourth, the STDN of today relies heavily on voice and teletype interfaces for the conduct of its operations. These methods are normally slower and less accurate than automated techniques. Current procedures occupy significant portions of NOCC workload by requiring the monitoring of "positive" or nominal information.

Impacts Of The TDRSS Era

During the TDRSS era, the concept of scheduling limited passes over each ground station will no longer be applicable because of the near continuous capability of TDRSS to view LEO spacecraft. Times for return link data transmission and forward link tracking and command signals will not be as rigidly confined as in the past. TDRSS users will all employ the same standardized ground sites, and the near real time relay of data has implications in the area of data quality assurance that have been absent in the past. The GSTDN users as well will interface with standardized ground station equipment that will no longer be constantly reconfigured to handle specialized needs. The GSTDN, too, will supply near real time data transmission from spacecraft to user. Large increases in system automation will be seen in the TDRSS era. These will add speed and accuracy to the monitoring functions of the NOCC. Routine status reports will no longer require voice loops or teletype messages, and each network element will have access to the information it needs when it needs it, with no extraneous information included.

COMPARISON OF PRESENT STDN AND TDRSS ERA OPERATIONS

PRESENT STDN OPERATIONS

- STORE AND FORWARD DATA TRANSMISSIONS
- COVERAGE LIMITED BY GEOGRAPHY FOR LEO USERS
- SOME STATIONS CONFIGURED WITH SPECIAL HARDWARE/SOFTWARE PACKAGES
- "POSITIVE REPORTING" USING VOICE/TTY INTERFACES

PLANNED TDRSS ERA OPERATIONS

- NEAR REAL TIME DATA TRANSMISSION FROM TDRSS AND GSTDN
- COVERAGE AVAILABLE FOR 80-100% OF ORBIT DEPENDING ON ORBIT HEIGHT
- STANDARDIZED S-BAND SUPPORT SYSTEMS FOR TDRSS AND ALL GSTDN GROUND SITES

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Introduction

KEY ASSUMPTIONS WERE ESSENTIAL TO THE ANALYSIS

All results of the Phase I analysis are highly dependent upon five major assumptions which served as a starting point for the detailed analysis.

Satellite Compatibility

Satellite compatibility with either TDRSS or GSTDN, but not both, implies a fully operational, TDRSS era configured STDN. The implications of the transition from a ground tracking network (and the associated satellite carryovers) to the STDN with a TDRSS are reserved for Phase 2 of this study.

Shuttle

Assuming that Space Shuttle utilizes TDRSS as prime support and GSTDN as back-up is consistent with available information. This study addresses the implications of simultaneous support of two operational space shuttles.

Automation Of TDRSS Ground Site

To minimize costs, it was assumed that the TDRSS contractor would automate the White Sands ground station to an extent consistent with current state of the art capabilities. The personnel positions assumed for the TDRSS ground station include: scheduler (1), computer operators/technicians (2), technical support (4), communications (2) and a station manager (1). Parenthetical numbers are estimated personnel at each position.

Automation and Standardization of GSTDN Sites

GSTDN was assumed to incorporate the Digital Data Processing System (DDPS) Phase II, Tracking Data Processing System (TDPS), and Spacecraft Command Encoder (SCE) characteristics. As such, each orbital support station would nominally require 2-3 personnel per link supported at the station, per shift.

GSTDN Configuration

A minimum of three GSTDN sites was assumed to always exist. This assumption was based on the geometrical desirability of maintaining a net of ground stations spaced 120 degrees apart in longitude around the earth.

KEY ASSUMPTIONS

- SATELLITES ARE COMPATIBLE WITH EITHER TDRSS OR GSTDN, BUT NOT BOTH
- SPACE SHUTTLE UTILIZES TDRSS AS PRIME SUPPORT WITH GSTDN BACK-UP
- TDRSS GROUND STATION IS HIGHLY AUTOMATED WITH APPROXIMATELY 10 POSITIONS PER SHIFT
- GSTDN IS TDPS/DDPS/SCE EQUIPPED AND HAS MINIMUM MANNING
- A MINIMUM OF THREE GSTDN SITES WILL ALWAYS EXIST

Introduction

ANALYSIS KEYED ON ADHERENCE TO DEFINITION AND ACCOMPLISHMENT OF GOALS

The STDN control concept definition and goals were the basis for this analysis.

Foundation Of The Analysis

The definition and establishment of goals were fundamental to the development of an operations control concept. In addition to providing the foundation for the study effort, the definition and goals provided a context for the analysis evolution. The STDN was viewed as providing a set of services to network users. A control concept definition was formulated which contained the attributes desired by both the network and its users. Subsequently, goals were derived from the operational definition and the objectives of the TDRSS era STDN which provided a means by which alternative control concepts could be evaluated.

Operational Definition

RELIABLE SERVICE addresses the probability that the STDN will perform as required for a given time under predefined conditions. In data communication systems, reliable service is often specified in terms of bit error rate (BER) and block error rates. RESPONSIVENESS is the ability to react to requests within established time and quality criteria. The ability of the STDN to provide a user unscheduled contact with his spacecraft on the next orbit could be a measure of responsiveness. Providing a data communications service which obtains spacecraft data and transfers it to the user for analysis with the minimum of transfer-induced errors is a measure of HIGH QUALITY service.

Control Concept Goals

Network TRANSPARENCY implies that the STDN presents a minimum set of obstacles to the user's ability to interact with his spacecraft. A representative example of network transparency is a caller's interaction with the AT&T telephone system. UNIFORMITY of operations directly addresses the consistent operation of user/network interfaces over the total spectrum of loading as well as individual network element operational consistency. The ability to adjust or adapt to change characterizes FLEXIBILITY. Specifically, for the STDN operational control concept, it is the ability to adjust or adapt to both near-term and long-term loading, specific requirements, mission, and technological and organizational changes. In the context of an operational control concept, EFFICIENCY implies the proper allocation of activities between man and machines (i.e., machines manipulate data and perform calculations - men make decisions). Additionally, it reflects the proper allocation of responsibility for STDN and spacecraft activities between network and POCC/user personnel, respectively.

OPERATIONAL DEFINITION

A CONTROL CONCEPT IS THE METHOD BY WHICH NETWORK RESOURCES ARE MANAGED TO PROVIDE

- RELIABLE
- RESPONSIVE
- HIGH QUALITY

SERVICE TO SUPPORT USER REQUIREMENTS.

CONTROL CONCEPT GOALS

- ENHANCE NETWORK TRANSPARENCY TO THE USER
- MAINTAIN UNIFORMITY OF OPERATION
- ENSURE FLEXIBILITY TO ACCOMMODATE LOAD VARIATIONS
- ENHANCE OPERATIONAL EFFICIENCY

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ANALYSIS APPROACH

Analysis Approach

A SYSTEMATIC APPROACH GUIDED THE DEVELOPMENT OF THE PRINCIPAL CONTROL CONCEPT

Six fundamental steps were performed to evaluate alternative control concepts in order to develop the Principal Control Concept.

Generic Concept Definition

To bound the analysis of alternative control concepts, two generic control concepts were defined. centralized and decentralized. As the analysis proceeded, it was necessary to define a third generic concept which would categorize alternatives between the bounds. This third concept was specified as matrix.

Segmentation Of Network Operations

Because of the complex nature of the STDN operations, it was desirable to determine the feasibility of dividing these operations into independent, interconnected parts. The ability to accomplish this aim reduced the complexity of control concept analysis. Thus, the preferred methodology for each task could be combined to construct the Principal Control Concept.

Alternative Methodologies

Alternative methods of performing each task were defined. Each alternative was categorized as centralized, decentralized or matrix control. The alternatives were differentiated by their information flows, interface requirements, and delegation of work, responsibility and authority.

Methodology Evaluation

A quantitative and qualitative evaluation of each task control methodology was undertaken on a task-by-task basis. The quantitative analysis tools identified in the figure were utilized to gain specific figures of merit for each alternative. These figures of merit included number and percent of conflicts, distributions of link free time, etc. The qualitative analysis applied an understanding of current and planned network operations to each alternative to identify advantages and disadvantages.

Methodology Selection

The preferred control methodology for each task was selected by considering its quantitative and qualitative advantages and disadvantages in terms of the control concept definition and goals

Principal Control Concept And Alternatives

The Principal Control Concept was synthesized by combining the preferred control methodology for each task. Alternatives to the principal concept may be derived by combining the alternative control methodologies in different ways.

The above steps are further discussed in the following pages. In this narrative, the first two steps are discussed independently while the remaining elements are combined into a single unit describing the selection of the Principal Control Concept.

ANALYSIS APPROACH

- DEFINE GENERIC CONTROL CONCEPTS
- SEGMENT NETWORK OPERATIONS INTO INDEPENDENT CONSTITUENT TASKS
- IDENTIFY ALTERNATIVE CONTROL METHODOLOGIES FOR EACH TASK
- EVALUATE ALTERNATIVE CONTROL METHODOLOGIES
 - QUANTITATIVE ANALYSIS
 - MISSION LOADING MODEL
 - CONFLICT ANALYZER
 - ZERO-ORDER CONFLICT RESOLVER
 - SYSTEM QUEUEING MODEL
 - QUALITATIVE ANALYSIS
- SELECT PREFERRED ALTERNATIVE
- CONSTRUCT PRINCIPAL CONCEPT FROM SELECTED ALTERNATIVES

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Analysis Approach

IDENTIFICATION OF GENERIC CONTROL CONCEPTS

All alternative control concepts developed for the operations tasks fall within three generic categories which describe the distribution of workload, responsibility, and authority.

Generic Concepts

In order to develop the alternative control methodologies for each operations task, generic control concepts were defined. Originally, two control concepts, centralized and decentralized, were defined as bounds for the alternatives. Subsequently, it was found necessary to define the matrix control concept which lies on the spectrum between centralized and decentralized and which gives the NOCC the ability to vary the degree of centralization/decentralization.

The significant differences between the three generic control concepts have to do with the distribution of workload, responsibility, and authority. WORKLOAD refers to the actual performance of the task, such as scheduling, routine service, etc. RESPONSIBILITY implies the liability for ensuring that the workload is performed and that the directed actions are executed. AUTHORITY is defined as the power to cause specific actions to occur.

Centralized

In the centralized control concept, all functions are centered at the NOCC. The NOCC is solely allocated all work, responsibility, and authority for the performance of the task. In the centralized control concept, this allocation of the functions to the NOCC is permanent and no means are provided to decentralize any of the functions.

Decentralized

In this concept, all functions are permanently assigned to the users. The users perform the work of the task, have the responsibility for the performance, and have the authority over the task. The NOCC is essentially assigned the role of a user and has the capability to monitor but has no capability to centralize the functions.

Matrix

A matrix control concept is essentially defined to lie within the spectrum between the other two concepts. There exists, however, one other important distinction between the matrix concept and the other two. In both the centralized and decentralized concepts, the assignment of functions was a permanent assignment, either to the NOCC or to the users. In the matrix concept, the authority is permanently assigned to the NOCC. However, in maintaining the authority, the NOCC has the capability to delegate any

degree of work and responsibility to the users. This delegation is a temporary one and is done by the NOCC to maximize both service to the user and efficiency. By delegating varying degrees of work and responsibility, the NOCC can configure the matrix concept to operate totally centralized or nearly decentralized.

GENERIC CONTROL CONCEPTS

CENTRALIZED

ALL FUNCTIONS CENTERED AT THE NOCC

- WORK NOCC
- RESPONSIBILITY NOCC
- AUTHORITY NOCC

DECENTRALIZED

ALL FUNCTIONS PERMANENTLY ASSIGNED TO USERS

- WORK USERS
- RESPONSIBILITY USERS
- AUTHORITY USERS

MATRIX

VARIOUS FUNCTIONS DELEGATED TO USERS BY NOCC

- WORK NOCC ——— USERS
- RESPONSIBILITY NOCC ——— USERS
- AUTHORITY NOCC

Analysis Approach

SEGMENTATION OF STDN OPERATIONS INTO INDEPENDENT TASKS

All current and planned STDN operations were segmented into four operations tasks which, while interconnected, could be considered as fundamentally independent for purposes of deriving control methodologies.

Independency

The results of the survey of current network operational procedures and plans for the TDRSS era STDN allowed segmentation of network operations into four fundamental operations tasks. The activities and procedures conducted within each task area are executed in a manner which produces only second order interactions among the tasks. For example, the procedures for scheduling do not directly interact with procedures for providing routine service. Since this control concept analysis addressed the "how" of STDN operations, it is the independence of the "how" associated with each task which is of fundamental importance. Thus, alternative control methodologies (i.e., the method with which each task is executed) were developed and evaluated separately for each task.

Scheduling

The task of scheduling is the process by which each event associated with STDN operations (spacecraft contact, maintenance, etc.) is allocated a segment of time which is not in conflict with any other STDN event.

System Integrity

System integrity is the process by which network operations management insures that STDN elements are capable of performing to established standards. The components of system integrity are. Routine Integrity Assessment, Network Simulations; and Tests. Routine integrity assessment is the process by which real time estimates of STDN performance are made. Network simulations encompass the activities of appropriate network elements and users to establish STDN performance capabilities prior to an actual event. Tests address the activities undertaken by STDN elements to establish performance standards for new and/or existing hardware and software.

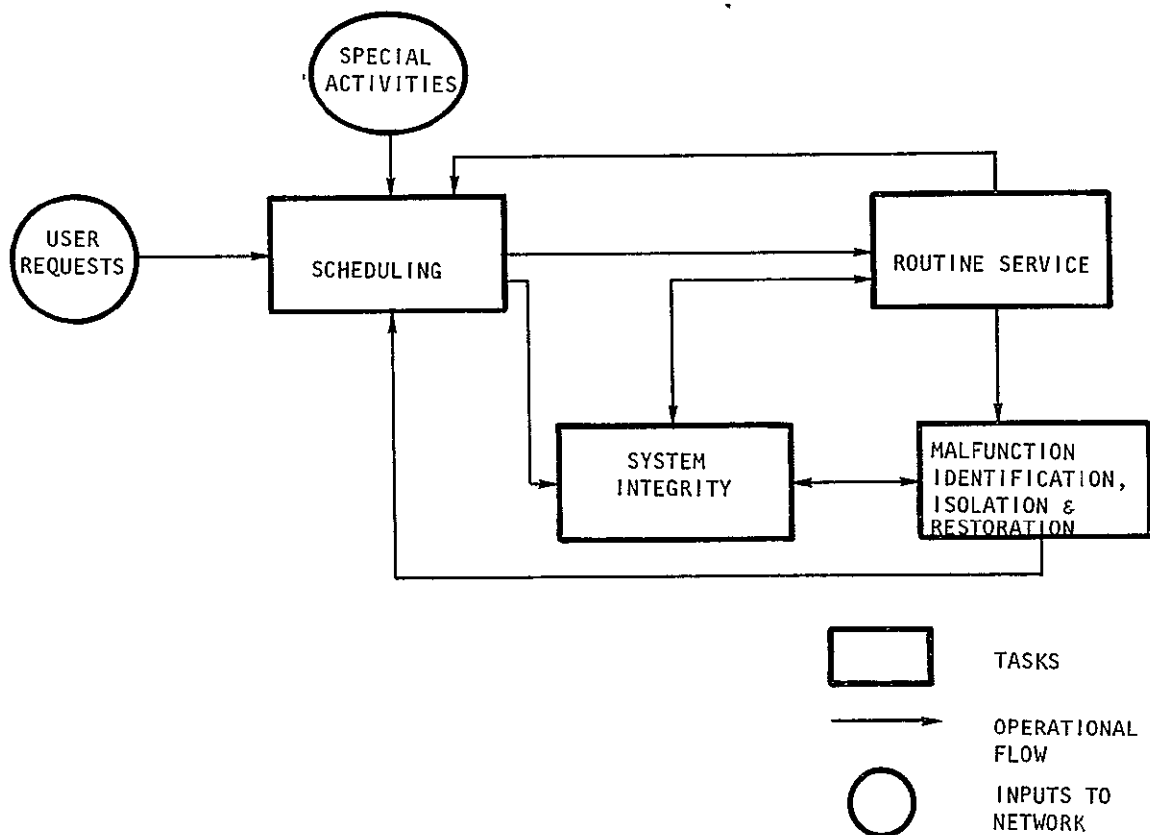
Routine Service

The method by which the STDN accomplishes contact with a spacecraft and transfers commands and/or telemetry/experimental data between that spacecraft and the POCC/user is considered routine service.

Malfunction Identification, Isolation and Restoration

This task specifies the manner in which performance anomalies are recognized and isolated to specific STDN and/or user elements. Additionally, it is the process by which restoration actions are directed to remove the source of the anomaly.

SEGMENTATION OF NETWORK OPERATIONS



Analysis Approach

SYNTHESIS OF PRINCIPAL CONTROL CONCEPT

A preferred control methodology for each operations task was selected from among several alternatives based on a quantitative and qualitative analysis. These preferred control methodologies were then combined to form the Principal Control Concept.

Alternative Task Control Methodologies

Two primary control methodologies were developed for each task. These alternatives represent the generic bounds of centralized and decentralized control. Where appropriate, further alternatives were defined which were categorized as matrix alternatives. The requirements for the matrix alternative were driven by the characteristics of users and STDN operations

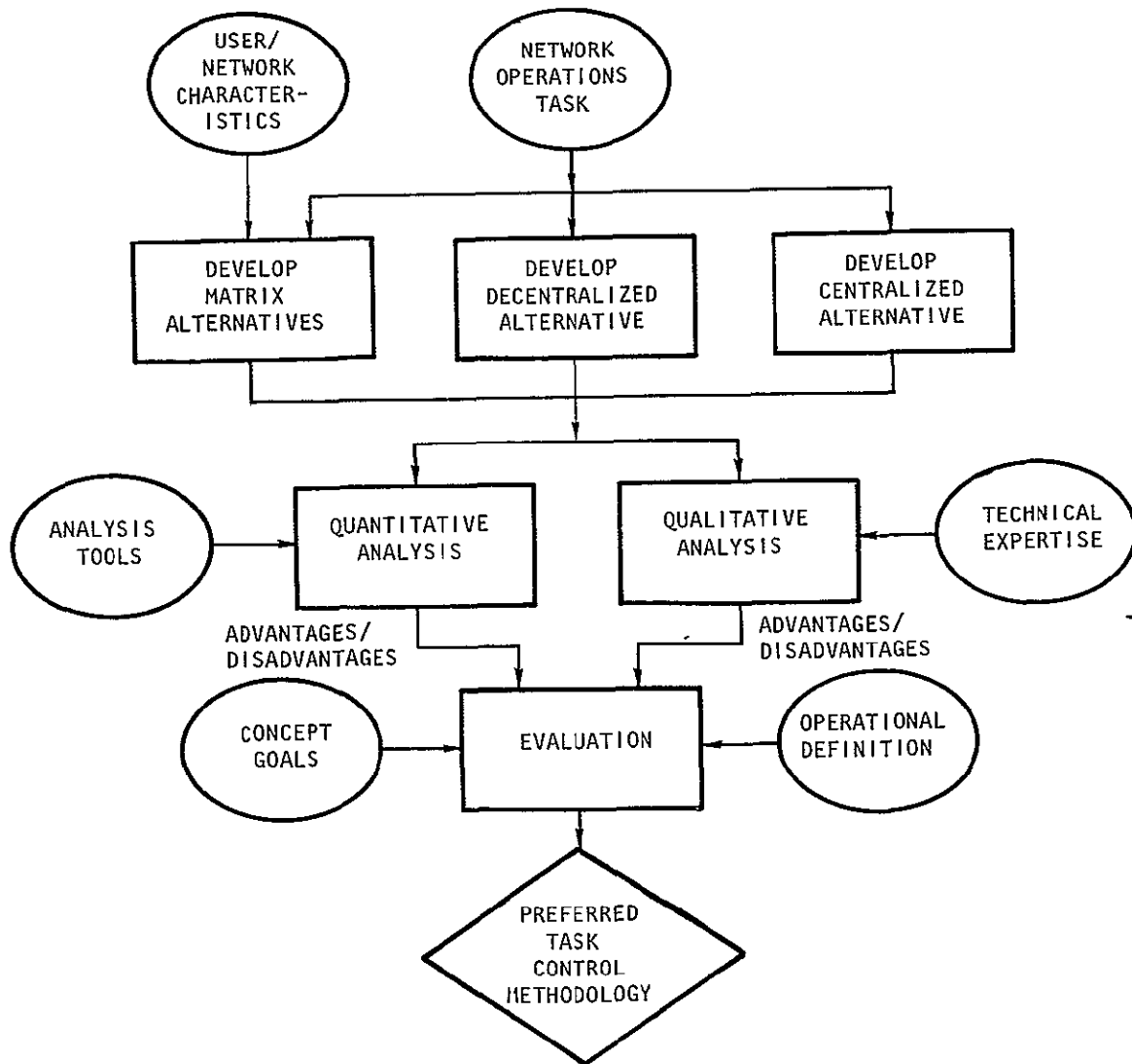
Selection Of Preferred Alternative

Quantitative and qualitative analysis techniques were utilized to evaluate the task control methodologies on an independent task-by-task basis. The quantitative analysis tools are described in Appendix A. The Mission Loading Model and Conflict Analyzer were utilized to assess the impacts of load variations on available free time and conflicts. Additionally, the Conflict Analyzer and Zero-Order Conflict Resolver were used to evaluate alternative scheduling methodologies. The System Queuing Model was initially used to perform acquisition technique comparisons. TDRSS operation in this area was solidified during the course of this analysis. Thus, this portion of the analysis was not pursued. By comparing the qualitative and quantitative characteristics of each alternative in terms of the previously defined goals, a preferred control methodology was selected for each task.

Principal Control Concept And Alternatives

Since the operations tasks were fundamentally independent for purposes of developing the control methodologies, the Principal Control Concept was defined by combining the set of preferred control methodologies for each task. Alternative control concepts are then specified by combining the alternative control methodologies for each task in different though compatible sets.

METHODOLOGY FOR
SYNTHESIS OF PRINCIPAL CONTROL CONCEPT



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PRINCIPAL CONTROL
CONCEPT FORMULATION

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Principal Control Concept Formulation

ROADMAP TO PRINCIPAL CONTROL CONCEPT

The Principal Control Concept is presented in the following section by first defining the Automated Scheduling Routine (ASR) and the Control and Status Monitoring System (CASMS). Next, the preferred control methodology is developed for each operations task by presenting the characteristics of the selected methodology, selection rationale, and the associated information flow and interfaces.

Organization of Material

The material in the following section details the formulation of the Principal Control Concept. Two automated routines, the Automated Scheduling Routine (ASR) and the Control and Status Monitoring System (CASMS), are basic to all the alternatives and are, therefore, presented and discussed first. Next, each operations task is addressed sequentially and a preferred control methodology is developed. Only the preferred methodology is presented in this section. Details of the alternatives for each operations task are presented in Appendix D. For each operations task, the control methodology is presented by first discussing the characteristics of the control methodology, then the selection rationale, and, finally, the information flow and interfaces.

After the control methodologies for each operations task are presented, the Principal Control Concept is presented along with a summary of its advantages.

Characteristics of Selected Methodology

The discussion of the control methodology for each of the operations task is initiated with a discussion of the selected control methodology. This discussion characterizes the control methodology and discusses the important aspects of the operations task.

Selection Rationale

The advantages and disadvantages of a totally centralized or totally decentralized approach to accomplishing the task are presented as part of the qualitative analysis. Similar comparisons also may be made of differing methods of accomplishing facets of the total task (i.e., performance parameter monitoring versus data inspection for data quality measurements as part of System Integrity). Quantitative measures are presented with discussions of their applicability to preferred alternative selection accompanying them. Possible system tradeoffs are also addressed for some of the operations tasks.

Information Flows and Interfaces

Information flows for each preferred control methodology are described and diagrammed. Interfaces with the other NASA organizations are discussed, along with a description of the means by which the NOCC can control the degree of centralization/decentralization for those methodologies employing a matrix concept

The Principal Control Concept

A summary of the four preferred alternatives is presented along with a discussion of the range they occupy between centralization and decentralization. Additionally, specific advantages of the Principal Control Concept are presented and summarized.

ROADMAP TO PRINCIPAL CONTROL CONCEPTS

- AUTOMATED ROUTINES
 - AUTOMATED SCHEDULING ROUTINE (ASR)
 - CONTROL AND STATUS MONITORING SYSTEM (CASMS)
- CONTROL METHODOLOGY FOR EACH OPERATION TASK
 - CHARACTERISTICS
 - RATIONALE
 - INFORMATION FLOWS AND INTERFACES
- PRINCIPAL CONTROL CONCEPT

THE BDM CORPORATION

Principal Control Concept Formulation

AUTOMATED SCHEDULING ROUTINE (ASR) - A MULTI-CAPABLE NETWORK MANAGEMENT TOOL

The automated scheduling routine is a powerful computer algorithm that not only produces the network schedule, but also serves as an interactive network tool used for planning and conflict resolution.

General Service/Class Priority System

To take advantage of long TDRSS view times and large amounts of free time, service requests would assume one or a combination of the following forms: generic, specific, quasi-generic. Generic requests are those which must be periodically scheduled but the time at which the event occurs is, within specified rules, not critical. Specific requests represent the other end of the request spectrum. These events require scheduling at the precise time requested. Quasi-generic requests are specific requests with increments about their initiation times. For example, a request for a return link data dump support may specify a desired start time plus or minus "X" minutes. Therefore, a request class priority scheme can be adopted as part of a scheduling approach. In this scheme all satellites are assumed to have a single priority. However, specific, quasi-generic and generic requests would have the indicated priority ranking. Specific requests would always be scheduled first, quasi-generic second, and generic last. Also the request type and hence priority could change as a function of time. For example, periodic preventive maintenance (PM) could be considered initially as generic requests but as the time since the last PM increases, the next required PM activity assumes a more "specific" nature.

Identification of Scheduling Alternatives/Interactive Capability

There will exist situations when the algorithms designed to supply conflict free schedules may not be able to do so without violating built-in program constraints. This may occur during periods of heavy loading or when priority considerations cannot be resolved. In keeping with the goal of transparency, it is desirable for the system to generate possible alternatives for service at these times. If a decentralized mode is selected for the ASR, the users may then be given available choices that are compatible with the scheduling algorithm which are close to their original requests. If a centralized mode were selected, this information would be given to the NOCC. In the same way, a user could make numerous requests of the program, be informed of the impact that each would generate and select from among them. This flexibility of the interactive capability gives the NOCC the ability to minimize its routine contact with the users and gives the users the information needed to request schedule changes.

Balance Between Forecasting and Near-Term Scheduling

To facilitate project support planning, schedules must be produced and service "guaranteed" (within limits) with sufficient advance notice. This implies that users can define their needs far enough into the future with

enough confidence for them to be entered into the ASR. For the orderly functioning of the ASR, the terms "define their needs" and "far enough into the future" must be carefully examined and judicious choices made for their specification.

The network must also be responsive to the needs of users which arise unexpectedly or within a short period before the support is needed. Requirements for supplementary tracking contacts or an orbital maneuver needed to observe some phenomenon (e.g., solar flares for OSO) may occur during the execution of "guaranteed" service, and the ASR should be capable of incorporating these requests in real time with a minimum impact on the remainder of the users. Again, a thorough analysis of the problem must be made before a "cut-off" point is chosen after which all inputs are considered "interrupts" rather than scheduled entries. An alternative to this scheme is a constantly updated schedule with no deadlines at all. The important difference seen between the ASR and present methods is the potential reduction in lead-times from days to hours, and the automated real time rescheduling or presentation of alternatives which permit POCCs to perform the work and assume the responsibility for their own scheduling.

NOCC Authority Over Matrix Control

The ASR is designed to support a matrix control concept. As such, the ASR permits the scheduling function to be almost entirely decentralized with all interfaces being between the ASR and the users. In this configuration the NOCC would monitor the operation of the ASR. However, the ASR also can be configured to be totally centralized. In this case the users still enter requests directly to the ASR but no scheduling changes are made without NOCC approval. Varying degrees of centralization/decentralization can be achieved by the NOCC by modifying the ASR to decentralize types of events, specific users, events with certain lead times, etc.

AUTOMATED SCHEDULING ROUTINE

- RESOLVES CONFLICTS INVOLVING "GENERIC" SERVICE
- IDENTIFIES UNRESOLVABLE CONFLICTS AND SUPPLIES ALTERNATIVES
- CLASS PRIORITY SCHEME
- LONG LEAD-TIME SCHEDULING AND REAL TIME RESCHEDULING CAPABILITY
- FLEXIBLE INTERACTIVE CAPABILITY

Principal Control Concept Formulation

FEASIBILITY OF AN AUTOMATED SCHEDULING ROUTINE (ASR)

Through quantitative analysis, the feasibility of defining an Automated Scheduling Routine (ASR) that will provide maximum flexibility in meeting near-term service requests, while concurrently providing alternatives for conflict resolution, has been supported.

Conflict Analyzer

A computer program (Conflict Analyzer) was developed that simulated the number of satellites using the MA and SA forward and return links for a 12-hour period. Each minute where the capacity of the link was exceeded was flagged as a conflict, and data on the total number of conflicts, percentage of contacts in conflict, total system free time, and probability of finding a free slot of length "x" or greater were tabulated.

The data indicated that for baseline loads only a small percentage of total contacts were in conflict for simulated random access to the scheduler by the 18 missions of the Mission Model. Using the Mission Loading Program, it was demonstrated that more than 90% of the total available service time on SA and MA return links was free, and more than 50% of the total MA forward link time was free. A cumulative distribution of free time is shown in the sensitivity analysis section demonstrating the probability of providing service in a "slot" of free time that is equal to or greater than a user's minimum requirement. The large amounts of free time at baseline loading, in addition to the larger view times of the TDRSS, suggest the feasibility of a computer algorithm that could "pack" or "slide" scheduled service in some near-optimal manner. The technique would provide maximum flexibility in incorporating near-term service requests and in providing alternatives for the resolution of conflicts.

Conflict Resolver Program

The conflict analyzer simulated random entry to the schedule with all users requiring service at specific times in their orbit. When conflicting users were treated as "generic" (i.e., accepting a given amount of service during any part of their orbit) small shifts (1-3 minutes) in their schedule resolved over 50% of first-order conflicts at baseline loading. These first-order conflicts could occur when the capacity of a channel was exceeded by one user. Because of the "zero-order" nature of the conflict resolver, larger shifts (5-8 minutes) caused a breakdown of the conflict resolver. However, the actual ASR would incorporate scheduling techniques which are far more powerful than the conflict resolver used here, and would show significantly greater ability to resolve the higher order conflicts.

Need for Sophistication

The analysis of the baseline loading supported the feasibility of an automated scheduling algorithm. In later sections, a sensitivity analysis is presented which investigated the impact of varying the loading. The major impact was on the number of conflicts produced and their severity. This indicated that while the concept of an ASR was feasible, it needed to be a sophisticated routine employing the latest scheduling techniques.

FEASIBILITY OF AUTOMATED SCHEDULING ROUTINE

- CONFLICT ANALYZER INDICATED VERY FEW CONFLICTS FOR TOTALLY RANDOM SERVICE SCHEDULING AT NOMINAL LOADING
- DAILY LOADING PROGRAM INDICATED SIGNIFICANT FREE TIME ON TDRSS LINKS
- "ZERO-ORDER" CONFLICT RESOLVER DEMONSTRATED OVER 50% OF "ORDER 1" CONFLICTS COULD BE RESOLVED IF REQUESTS WERE CONSIDERED "QUASI-GENERIC"

THE BDM CORPORATION

Principal Control Concept Formulation

CONTROL AND STATUS MONITORING SYSTEM (CASMS) AUTOMATES STDN INTERFACES

CASMS is a hardware/software package that provides summaries of network status parameters and real time estimates of data quality.

Status Monitoring

Information pertaining to status, STDN element configuration, and the occurrence of events must be exchanged between the NOCC, network elements, and users during the normal course of network operations. The CASMS is used to automate the transfer of this information. CASMS can receive status and event indications via "level type" signals activated by switch positioning at the transmitting element. For example, a green status indication could be transmitted to CASMS from a GSTDN site by placing the "STATUS" switch on a console to the appropriate position. Signals received by CASMS are catalogued, stored and presented for visual review by operations management personnel. Configuration information may be transmitted to CASMS via formatted messages which are also catalogued, stored and presented for visual review. The software within CASMS then provides periodic status and/or event mark occurrence information either periodically or on an "as changed" basis. Additionally, an interrogate/response capability is provided within CASMS which allows acquisition of specific information on an "as needed" basis.

Data Quality

CASMS also has the capability of providing real time estimates of data quality. These measures are necessary for the NOCC to obtain measures of STDN performance as it fulfills its data transfer function. Two fundamentally different techniques of obtaining real time data quality measures were considered in the analysis: performance parameter monitoring and data inspection. These will be summarized in a later portion of this section and are covered in detail in Appendix E. CASMS can support either method of data quality measurement. However, the hardware and software requirements are significantly different for the two approaches. Additionally, the interfaces between CASMS and the NASCOM data communications network change as a function of the chosen data quality estimating approach. In general, CASMS tends to be significantly more complex in both hardware and software when supporting the data inspection technique. The performance parameters monitoring scheme tends to minimize equipment and software development requirements.

CONTROL AND STATUS MONITORING SYSTEM (CASMS)

- ACCEPTS AND DISPLAYS CURRENT STATUS OF NASCOM/TDRSS/GSTDN/POCC FOR UPCOMING SERVICE
- ACCEPTS AND DISPLAYS COMPLETION OF EVENT SEQUENCES
- PROVIDES REAL TIME ESTIMATES OF DATA QUALITY

Principal Control Concept Formulation

CHARACTERISTICS OF THE SELECTED METHODOLOGY FOR SCHEDULING

An automated scheduling routine supports a control methodology which centralizes a portion of the scheduling process and decentralizes other portions. The capability to enforce centralized scheduling on the portion which is nominally decentralized is retained by the NOCC.

Characteristics

Scheduling the STDN depends upon inputs from network elements as well as the users of that network. The ability to generate schedules which require minimal changes requires the "scheduler" to receive inputs sufficiently before the event to allow coordination and conflict resolution. Additionally, inputs must be received sufficiently close to the desired schedule time to minimize the chance that conditions will occur between input and event that will cause the event to be rescheduled.

Users of the STDN in the future, as now, will desire to make their scheduling inputs at different points in time. Some users may desire to input schedule requests far in advance of the service event to allow coordination of individual payload timelines among the experimenters utilizing the satellite. The coordination of the use of experiments on ATS may serve as an example. Approximately seven communications experiments are part of ATS-6. Service requests, input weeks in advance, may be required to allow each set of experimenters to appropriately access ATS and obtain their desired data. Alternatively, missions such as the Atmospheric Explorer (AE) may desire to schedule critical service as near to the time of actual occurrence as possible. In this manner data obtained from the previous contact can be analyzed and last minute adjustments to orbital parameters or command sequences made.

To support the need for variability of network element and user scheduling input time frames, an automatic scheduling routine was employed in all alternative methodologies defined.

Preferred Methodology

The preferred methodology allows selected users (GSFC POCC and JSC) to interact with the scheduling routine directly. Other users, (non-GSFC POCCS, DOD, JPL, foreign, etc.) with special requirements, input their requests to the NOCC. JSC is considered in the same manner as GSFC POCCS because of the unique nature of its scheduling requirements. As far as STDN resources are concerned, service to JSC has the effect of diminishing the TDRSS SA link resource by one for each Shuttle serviced. Once the required SA links have been scheduled, JSC access to the ASR allows determination of the effect of desired POCC access to Shuttle-contained payloads on link capability. For example, if two POCCs desire contact with their Shuttle payloads

simultaneously, this conflict can be readily identified. Use of the ASR allows last minute POCC decisions regarding contact with their Shuttle payloads and provides JSC the ability to orderly control POCC transmissions as well as JSC transmissions to the Shuttle. From the NOCC's viewpoint, JSC control of the Shuttle SA link is transparent to the STDN since the link has effectively been removed from the TDRSS resource for the portion of each Shuttle's orbit required. The ability to schedule far in advance also aids in the ability to coordinate STDN resources during periods when Shuttle is in orbit.

To allow orderly network scheduling in times of stress, the NOCC retains the ability of enforcing centralized control of the scheduling process on the GSFC POCCs and JSC. This enforcement occurs via NOCC inputs to the ASR. During times of stress NOCC operations management will affect the constraints portion of the ASR so as to cause all requests to be approved before addition to the existing schedule is attempted. Before approval or disapproval the NOCC operations management personnel can query the ASR with the POCC request to determine whether it can be scheduled or alternatively, what impacts (in terms of conflicts) on the schedule this service request would have

The nature of the automatic scheduling routine allows this centralization to occur without interface operation changes. GSFC POCCs input their requests via interactive terminal as in the unstressed or decentralized mode of operations. When the NOCC constrains the ASR to obtain approval before attempting request allocation to the existing schedule, the POCC may notice an increase in time before the ASR responds to his request. However, the interface operation remains unchanged.

SCHEDULING

- FOUR ALTERNATIVES WERE DEFINED
- ALL ALTERNATIVES EMPLOY AN AUTOMATED SCHEDULING ROUTINE
- SELECTED ALTERNATIVE UTILIZES MATRIX APPROACH

Principal Control Concept Formulation

SELECTION RATIONALE FOR SCHEDULING METHODOLOGY

The selection of a preferred scheduling methodology was based on a qualitative assessment of the defined alternatives supported by quantitative data pertaining to current network scheduling procedures.

Four Alternatives

Four alternative scheduling methodologies were defined. Two represented the generic concept bounds of centralized and decentralized. A third considered centralization of maintenance scheduling while decentralization of all user service requests was retained. The fourth alternative considered centralized maintenance scheduling and the centralization of non-GSFC user service requests. Decentralization of GSFC POCC service requests was retained. In all cases, JSC was considered in the category of a GSFC POCC.

Advantages and Disadvantages

The advantages and disadvantages of the bounding alternatives were first considered. Each particular advantage or disadvantage assumes more or less importance depending on the activity of the network. In fact, inspection of the advantages and disadvantages when considering loading, the control concept goals and qualities of the operational definition suggested that aspects of each bound were highly desirable depending on the actual network operational situation. In stress situations, for example, where major perturbations can potentially be made to the existing schedule (e.g., a spacecraft emergency) the penalty incurred for centralizing scheduling may be far outweighed by having a single point of accountability. Further information pertaining to these specific trade-offs is provided in Appendix D.

Matrix Concept

These considerations then led to the selection of a matrix control approach to scheduling wherein the NOCC retained the capability to adjust the degree of centralization or decentralization used to affect maintenance and GSFC POCC service scheduling.

CONCEPT COMPARISONS

ADVANTAGES

CENTRALIZED

- NETWORK CONSIDERATIONS DIRECTLY IMPOSED ON USERS
- MINIMAL POTENTIAL IMPACT ON CURRENT PROCEDURES
- LESS CHANCE OF OPERATOR ERROR
- POSITIVE CONTROL WHEN REQUIRED
- QUICKER RESOLUTION OF CONFLICTS
- SINGLE POINT OF ACCOUNTABILITY

DECENTRALIZED

- USER AUTONOMY
- FAST TURN-AROUND
- LOADING VARIATIONS HAVE MINIMUM IMPACT ON NOCC
- MINIMIZE ROUTINE NOCC WORKLOAD
- ALL USERS QUICKLY KNOW IMPACT OF S/C EMERGENCIES ON THEIR SCHEDULE
- ALL USERS MAKE OWN TRADE-OFF DECISIONS

DISADVANTAGES

CENTRALIZED

- HIGH NOCC ROUTINE WORKLOAD
- INCREASED REQUEST LEAD-TIME
- WORKLOAD A DIRECT FUNCTION OF NUMBER OF USERS
- SIGNIFICANT DELAYS IN PRODUCTION OF VALID SCHEDULE AFTER MAJOR PERTURBATION

DECENTRALIZED

- REQUIRES SIGNIFICANT CHANGE FROM CURRENT PROCEDURES
- CONFLICT RESOLUTION A MAJOR PROBLEM
- REDUCED CAPABILITY TO HANDLE SPECIAL REQUIREMENTS

Principal Control Concept Formulation

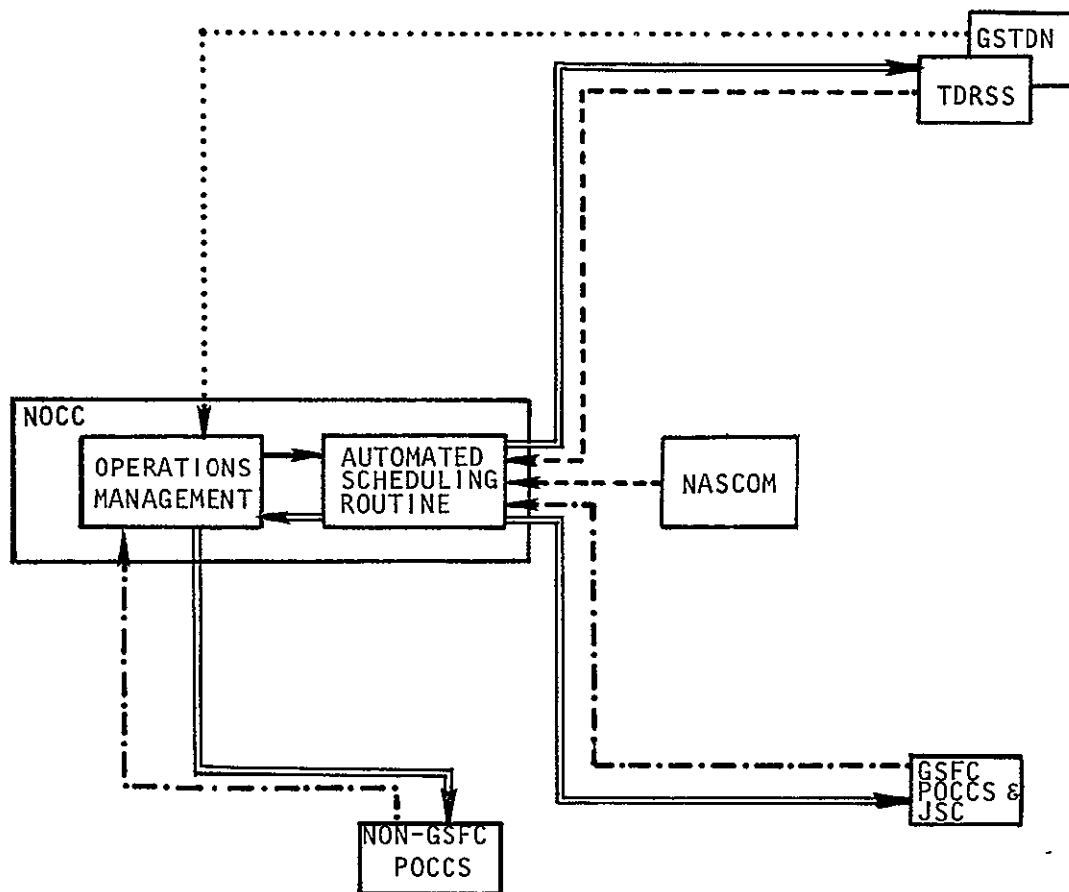
INFORMATION FLOW AND INTERFACES FOR SCHEDULING

The information flow for the preferred matrix control methodology focuses on the ASR and NOCC operations management.

The information flow for the preferred scheduling methodology is shown in the figure. NASCOM, STDN ground stations, GSFC POCCS, JSC and NOCC Operations Management have direct access to the ASR. Information is input to the ASR from interactive terminals located with each of the above identified elements. Non-GSFC POCCs interface with NOCC operations management. Service requests are submitted to the NOCC, either by voice, teletype or other written form of communication.

The ASR returns successful event scheduled or conflict information to those elements directly interacting with it. When conflicts are identified, the users in conflict and potential scheduling alternatives are provided. At a specified time, the ASR generates the total schedule for the next schedule period. It is made available for NOCC operations management approval, and, upon approval, provided to all affected network elements and users.

SCHEDULING INFORMATION FLOW



LEGEND

- NETWORK CONSTRAINTS & SPECIAL SERVICE REQUESTS
- - - - STATUS & CONFIGURATION
- MAINTENANCE OR TEST REQUESTS
- ==== CONFLICTS & ALTERNATIVES
- REQUESTS (SIMULATIONS, ETC)

Principal Control Concept Formulation

CHARACTERISTICS OF SELECTED METHODOLOGY FOR SYSTEM INTEGRITY

The preferred control methodology -- a centralized concept -- was developed by analyzing each of the components of integrity.

Components of System Integrity

System integrity consists of the three components previously defined in the segmentation of network operations: routine integrity assessment, network simulations, and special tests. These components were found to be relatively independent, much as is each network operations task. Hence, each component was analyzed sequentially and the best control for each component defined.

Centralized Control

The preferred methodology centralizes the control of each of these elements and hence results in a centralized approach to system integrity in toto. CASMS is a fundamental element in the selected methodology. It also served as the cornerstone of all alternatives defined for each of the task's components (see Appendix D).

The preferred methodology utilizes real-time data quality estimates to establish routine system integrity. Performance parameter monitoring was the selected technique for obtaining these real-time estimates. During simulations and tests, the event marks, configuration and status information must be exchanged between the NOCC, network elements and other participants in the system integrity activities. An automated approach to this requirement is characteristic of the preferred methodology. CASMS is utilized to both obtain the real-time data quality estimates and support the automation of the event mark/status information exchange.

SYSTEM INTEGRITY

- CENTRALIZED AND DECENTRALIZED ALTERNATIVES WERE DEFINED
- ALL ALTERNATIVES EMPLOY AN AUTOMATED CONTROL AND STATUS MONITORING SYSTEM (CASMS)
- THE SELECTED ALTERNATIVE CONTROL METHODOLOGY UTILIZES A CENTRALIZED APPROACH

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Principal Control Concept Formulation

SELECTION RATIONALE FOR SYSTEM INTEGRITY METHODOLOGY

The advantages and disadvantages of the various system integrity component alternatives indicated a centralized concept was the preferred control methodology for this task.

Real Time Data Quality Estimates

Two techniques were analyzed as approaches to obtaining real time estimates of data quality: performance parameter monitoring and data inspection. The comparison of these two techniques is summarized in the accompanying figure. Further discussion is provided in Appendix E. The potential requirement for duplications of user hardware and software was viewed as a major disadvantage to data inspection. Additionally, a performance parameter monitoring system provides the flexibility of supporting the other network operations tasks. These two factors were the fundamental drivers in the decision to adopt a performance parameter monitoring system for routine system integrity.

Link Testing

Pre/post contact link testing can support routine integrity assessment. This method of testing involves exercising communication links with test signals immediately prior to and after user-satellite contact. During the TDRSS era, this approach is seen as possessing significant disadvantages. Conflict analyses results demonstrated that link testing significantly increases a (by 50%) the number of contacts initially in conflict for a given load level or tracking duration. Concurrently, the capability of finding free time intervals of particular sizes decreases (this information is detailed in Appendix D).

Standardized equipment will be a salient feature of the TDRSS era STDN. High confidence statistical characterization of link performance should be possible from observations of performance during actual contacts. This information would be available from CASMS performance parameter monitoring statistics. This consideration then mitigates any additional confidence that would be gained by link testing. Indeed, use of link equipment for these tests may shorten the actual mean time between failures for actual contacts.

Network Simulations and Tests

A summary of the characteristics associated with the alternatives defined for this System Integrity component are shown in the table. The fundamental considerations which drove the selection of a centralized approach to this component were the uniform methods of conducting simulations and tests.

SELECTION RATIONAL FOR SYSTEM INTEGRITY

ROUTINE INTEGRITY

LINK TESTING

ADVANTAGES

- INTEGRITY VERIFIED USING ACTUAL EQUIPMENT IN SERVICE CONFIGURATION

DISADVANTAGES

- INCREASES TOTAL CONFLICTS BY 50%
- INCREASES NOCC ROUTINE WORKLOAD
- DECREASES NETWORK TRANSPARENCY BY REDUCING ABILITY TO PROVIDE UNSCHEDULED SERVICE
- DOES NOT TAKE ADVANTAGE OF GSTDN CHARACTERISTICS

REAL TIME DATA QUALITY ESTIMATES

CHARACTERISTICS OF PERFORMANCE PARAMETER MONITORING

- DATA COMMUNICATIONS INDUSTRY-STANDARD TECHNIQUE
- USES AVAILABLE INFORMATION
- PROVIDES ESTIMATES FOR WIDE RANGE OF GRANULARITIES
- ESTIMATES MAY BE PERIODIC OR CONTINUOUS

CHARACTERISTICS OF DATA INSPECTION

- POTENTIALLY REQUIRES SIGNIFICANT DUPLICATION OF USER HARDWARE AND SOFTWARE
- LIMITED INFORMATION AVAILABLE REGARDING DATA QUALITY
- SYSTEM DUPLICATES FUNCTION FOR WHICH INFORMATION EXISTS AND COULD BE USED

NETWORK SIMULATIONS AND TESTS

CHARACTERISTICS OF CENTRALIZED

- SINGLE POINT OF ACCOUNTABILITY
- UNIFORM METHODS OF CONDUCTING SIMULATIONS AND TESTS
- NOCC CAN BEST MAKE DECISIONS ABOUT NECESSITY OF SIMULATION OR TEST AND THEIR POTENTIAL IMPACTS ON OPERATIONS
- INCREASES NOCC ROUTINE WORKLOAD

CHARACTERISTICS OF DECENTRALIZED

- POCC AUTONOMY ENHANCED
- NECESSITY OF USER TO SCHEDULE SCARCE NETWORK RESOURCES MAY BE QUESTIONED BY NETWORK ELEMENTS
- ASSEMBLAGE AND COORDINATION OF NETWORK ELEMENTS BY NON-NETWORK PERSONNEL CAUSES "LANGUAGE" PROBLEMS
- LACK OF UNIFORMITY IN CONDUCTING SIMULATIONS LEADS TO CONFUSION

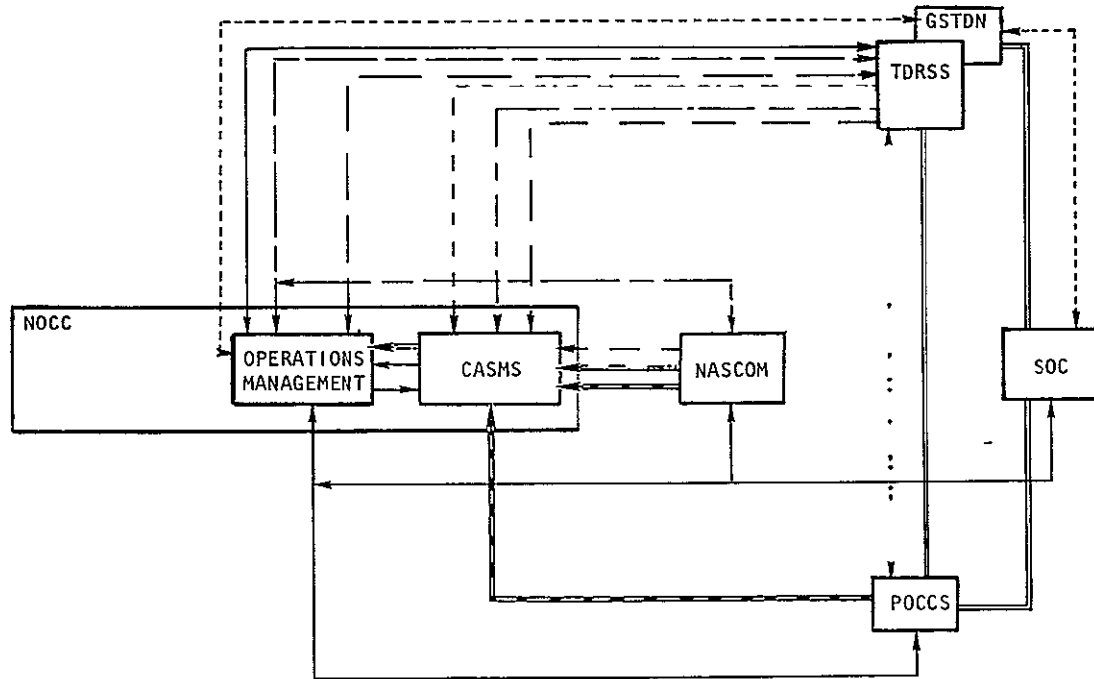
Principal Control Concept Formulation

INFORMATION FLOWS AND INTERFACES FOR SYSTEM INTEGRITY

The information flow for the coordination and determination of all system integrity components is focused at the NOCC.

The 9.6 Kbs digital communications channels are utilized as the performance parameter monitoring and event work interface between the NOCC and TDRSS/GSTDN. The performance parameters for which values are transmitted to CASMS are those specified in the TDRSS Performance Specification (Reference 4). The event marks are seen as "level" type switch activate signals transmitted from the ground sites to light indicator lamps and/or generate symbology on visual monitor displays. Low speed digital communications channels between the NOCC and POCCs/NASCOM support NASCOM transmission of Poly-Code Error Detection Status Words and POCC "level" event marks. Voice communications between operations management and the elements shown are provided for coordination and special directives. The 1.5 Mbs and 56 Kbs communication links between GSFC and STDN ground stations support the flow of simulation and test data.

SYSTEM INTEGRITY INFORMATION FLOW



LEGEND

- — — NETWORK ELEMENT TEST COORDINATION/NOCC DIRECTIVES
- - - - - ALTERNATE TEST DATA FLOW
- ===== ALTERNATE SIMULATION DATA FLOW
- · - · - NETWORK ELEMENT TEST EVENT MARKS
- · — · — PERFORMANCE PARAMETERS SAMPLED
- — — NETWORK SIMULATION COORDINATION/NOCC DIRECTIVES
- ===== SIMULATION EVENT MARKS
- — — TEST DATA (IF APPROPRIATE) FLOW
- · — · — PERFORMANCE PARAMETERS VALUES
- — — NETWORK SIMULATION DATA FLOW

Principal Control Concept Formulation

CHARACTERISTICS OF SELECTED METHODOLOGY FOR MALFUNCTIONS

The selected methodology uses centralized control for the identification, isolation, and restoration of network malfunctions.

Malfunction Identification

Anomalies that occur during the transfer of data from the spacecraft to the user can be identified in a number of ways. The user may indicate that the data being received is of poor quality, STDN station personnel may recognize the malfunctioning of particular equipments or NOCC data quality estimates may provide channel degradation indications. In this context, channel is used to describe the path or link from the spacecraft to the user. The preferred methodology utilizes the NOCC as the focal point for all reports of malfunctions. Additionally, the NOCC has the capability of detecting channel degradations independently of the STDN elements and users. System Integrity incorporated a performance parameter monitoring scheme to obtain estimates of routine system integrity. As indicated in Appendix E, this system can be used to signal channel degradations. The preferred methodology for this task utilizes aspects of the performance parameter monitoring system which resides in CASMS. Predefined performance thresholds are input to CASMS for each performance parameter. When these thresholds are crossed, CASMS identifies the condition and its specifics to NOCC operations management personnel. Thus, a near real time malfunction identification capability exists at the NOCC. Additionally, malfunctions which are detected by network elements (TDRSS, GSTDN, NASCOM) and users are made known to the NOCC.

Malfunction Isolation

Before restoral actions can be directed, the malfunction must be isolated to the portion of the channel causing the problem. Through the performance parameter monitoring system the NOCC retains a capability to independently assess the source of the malfunction. Additionally, the resources within the STDN ground stations and NASCOM are used to assist in the isolation effort. In the cases where isolation is difficult, the TDRSS simulation and/or SOC may be utilized to assist in problem isolation efforts.

Malfunction Restoration

Upon isolation, the NOCC will identify the responsible element to all interested parties. Additionally, corrective actions will be identified. In the preferred methodology, the NOCC is responsible for establishing the actions and timeframes in which the corrective measures will be accomplished. This is achieved through consultation with personnel at the source of the malfunction to allow reasonable actions and timeframes to be specified.

MALFUNCTION IDENTIFICATION,
ISOLATION AND RESTORATION

- TWO ALTERNATIVES DEFINED
- ALL ALTERNATIVES EMPLOY CASMS
- SELECTED ALTERNATIVE UTILIZES CENTRALIZED CONCEPT

Principal Control Concept Formulation

SELECTION RATIONALE FOR MALFUNCTION METHODOLOGY

Using speed of restoration as the major criterion, the advantages and disadvantages of the centralized and decentralized control concept favor a centralized control methodology for malfunction identification, isolation, and restoration.

Criteria

Speed of malfunction identification, isolation and restoration were considered to be the principle considerations in selecting the preferred control methodology. If this task is accomplished quickly, the length of disruptions in service caused by the network elements will be minimized, thus enhancing network transparency. Two basic alternatives were identified for control of this task. These alternatives correspond to the bounding concepts of centralized and decentralized control. A summary of the characteristics of these alternatives is provided in the figure.

Advantages and Disadvantages

In a centralized approach to this task, the technique of malfunction identification and restoration would tend to be uniform and faster than in a decentralized approach. With a single focal point, all problems would be seen and patterns of resolution established over a period of time. Spacecraft missions and POCCs/users vary over a period of time. Thus, the types of problems encountered and their resolution technique may require relearning on the part of new or different POCCs/users. Through the use of CASMS, the NOCC may in many cases be the first to recognize system problems. As indicated in Appendix E, threshold values for the performance parameter values may be specified over a wide range of granularities. By specification of "AMBER" zones or ranges where parameters are "mildly" out of tolerance, trending indicators could be developed. If CASMS produced trending indicators which pointed towards a movement to the "RED" or outage zone for significant periods of time, the NOCC could initiate restoration actions before users noticed any significant loss in data. In a decentralized approach the POCC/users could also monitor CASMS information. However, this would also require a "network expertise" at the POCC/user location. Complications, and hence delays, would be incurred--especially in the case of foreign POCCs and specialized users such as the DOD.

Decentralized control of this task has the potential to relieve the NOCC workload for certain low-order malfunctions (for example, a short data drop-out). Coordination between NASCOM, STDN site and the POCC may easily effect restoration. However, it would be the responsibility of the element identifying the problem to decide whether the problem was low-order or high-order, the latter calling for NOCC control. It would be a monumental effort to attempt to document all possible malfunctions so that decision trees could be developed. Without these decision trees, however, significant time could be

consumed before a malfunction was specified as higher order and in need of NOCC control. This condition would also significantly degrade the uniformity of network operations.

Although it is difficult to quantify speed of task execution, experience and the considerations discussed above suggest that the centralized approach will provide the most timely execution of this task.

<u>MALFUNCTION IDENTIFICATION, ISOLATION AND RESTORATION</u>	
<u>CHARACTERISTICS OF CENTRALIZED CONTROL</u>	<u>CHARACTERISTICS OF DECENTRALIZED CONTROL</u>
<ul style="list-style-type: none">• UNIFORM-RAPID PROBLEM-SOLVING TECHNIQUE ESTABLISHED OVER A PERIOD OF TIME• CASMS PROVIDES THE NOCC A CAPABILITY TO INITIATE RESTORAL ACTIONS BEFORE SIGNIFICANT OUTAGES OCCUR• MINIMUM IMPACT ON CURRENT PROCEDURES	<ul style="list-style-type: none">• POTENTIAL TO RELIEVE NOCC WORKLOAD FOR "LOW ORDER" MALFUNCTIONS• REQUIRES "NETWORK EXPERTISE" AT NOCC/USER LOCATIONS• POTENTIALLY SIGNIFICANT "LANGUAGE" PROBLEM IN DEALING WITH NETWORK ELEMENTS• SIGNIFICANT CHANGE FROM CURRENT PROCEDURES

Principal Control Concept Formulation

INFORMATION FLOW AND INTERFACES FOR MALFUNCTIONS

The information flow associated with malfunction identification, isolation and restoration is focused at the NOCC.

Malfunction Identification

As shown in the figure, the STDN ground stations and NASCOM provide performance parameter value inputs to CASMS. The interface which supports the routine integrity performance parameter transmission is applicable here also. Should any of the performance parameter thresholds be crossed, CASMS signals the situation and identifies specifics. The signaling of the condition may be accomplished by the lighting of an indicator lamp on a control console. Additionally, CASMS prints out the channel parameters and identifies which one (or more) were detected as out of tolerance. Voice communications are provided between the NOCC and NASCOM, POCCs, and STDN ground stations for the report of anomalous conditions.

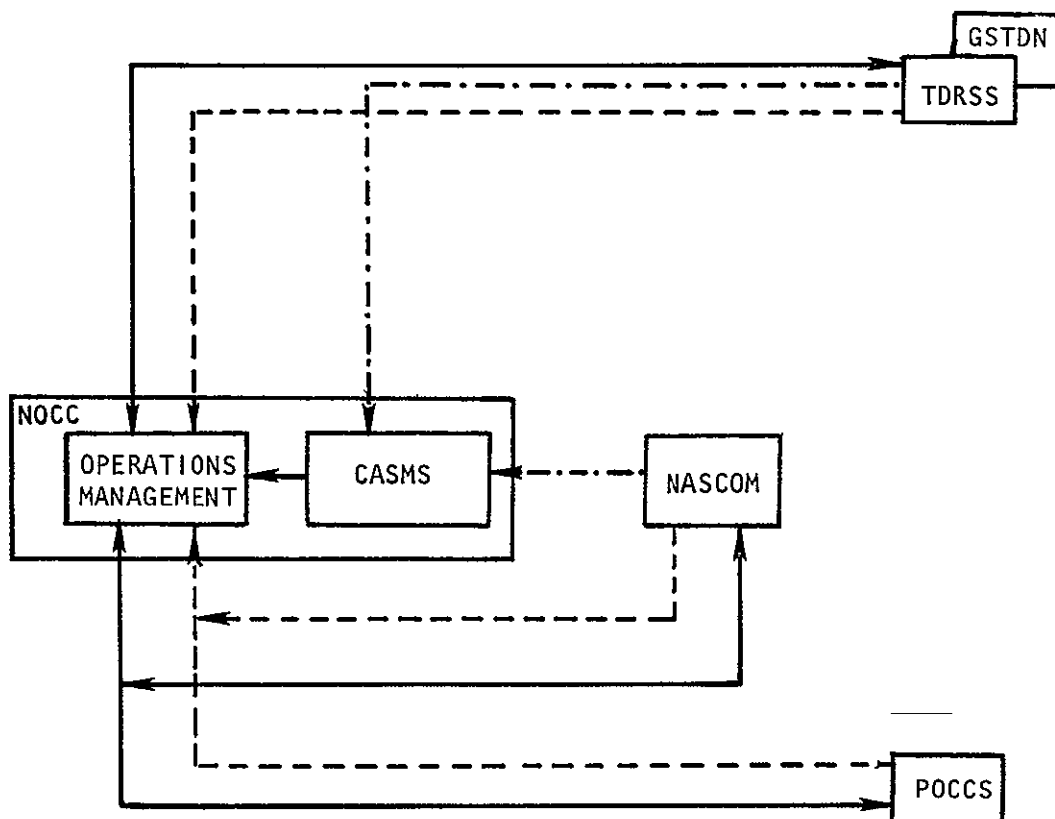
Malfunction Isolation

Technical support teams assisting the operations management personnel can extract from CASMS detailed parameter performance history data and/or current parameter measures for problem isolation. Once a problem is identified, the NOCC also enlists the assistance of all elements involved in assessing the condition of their respective equipments. Status information is then transmitted to CASMS as indicated in Systems Integrity. This request for element status checks may be automated via switch activations at the NOCC which signal the desire for status checks of equipment currently in use.

Malfunction Restoration

Voice communications are provided to allow consultation among the affected elements. Through this medium, corrective actions are identified and timelines for their accomplishment specified. Voice communications are utilized here because of the free form and ad hoc nature of many of the processes which occur during the overall execution of this task.

MALFUNCTION IDENTIFICATION, ISOLATION, AND RESTORATION INFORMATION FLOW



LEGEND

- PROBLEM IDENTIFICATION, NOCC DIRECTIVES
- - - PROBLEM REPORTS
- . - . - PERFORMANCE PARAMETERS

Principal Central Concept Formulation

CHARACTERISTICS OF SELECTED METHODOLOGY FOR ROUTINE SERVICE

The control methodology selected for routine service uses the matrix concept and is capable of varying the degree of centralization/dcentralization for network use once the network elements are assembled and established.

Routine service consists of two processes: assemble network resources and establish spacecraft-user link, and execution of forward and/or return link transmissions. The preferred methodology utilizes a centralized approach to accomplish the first process. Authority, responsibility, and work associated with ensuring that the correct network elements are ready to provide the scheduled support is centered at the NOCC. The NOCC also has the authority to delegate the work and responsibility of using the network, once established, to the users, if it is desired.

Decentralized Control

Each POCC may be delegated the work and responsibility of executing the information exchange with his spacecraft. At the completion of the contact, the POCC would mark the event with the NOCC and STDN elements. CASMS is utilized to automate the interfaces, to allow the uniform and smooth transition of control, and the mark of events.

Centralized Control

On the other hand, should the NOCC choose to centralize the execution of data transfer, CASMS will permit this. In this mode, users will still interface as before, but all data transfers will be executed only with positive approval of the NOCC.

ROUTINE SERVICE

- THREE ALTERNATIVES DEFINED
- ALL ALTERNATIVES EMPLOY CASMS
- SELECTED ALTERNATIVE IS MATRIX

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Principal Control Concept Formulation

SELECTION RATIONALE FOR ROUTINE SERVICE METHODOLOGY

The fundamental considerations of POCC/user-STDN interface operations, necessary NOCC workloads, and impacts on current procedures favored a matrix control methodology for routine service.

Advantages and Disadvantages

The advantages and disadvantages for centralized and decentralized control of routine service are summarized on the right. The importance of a particular advantage or disadvantage listed could be strongly influenced by the workload or "business" of the network. For example, in a centralized concept, NOCC routine workload at times when 10 spacecraft are in orbit will not be as high as it will be when 100 spacecraft are in orbit. However, for either situation the workload will be higher than for a decentralized approach. But, at low network loadings it may not be important that the NOCC is busier in a centralized approach. The evaluation isolated the considerations of load variation from others independently considering the two component elements of routine service.

Network Assembly and Establishment

The time periods in which network elements are "assembled" for service support and a link to the spacecraft is established, were judged to be most volatile or prone to minor upsets or delays. At these times, a single point of accountability and less chance of operator error (e.g. interpreting performance and status indicators) were weighted very high. Experience has shown that centralizing control for activities which tend to have mild perturbations reduces the impact on overall operations of a single perturbation (i.e., enhances transparency and uniformity of operations). The additional factor of foreign POCCs or users associated with the DOD presented the spectrum of potentially severe "language" differences during the volatile periods.

Network Utilization

On the other hand, once a link has nominally been established (i.e., the acquisition procedure has been executed) there will be a high probability (Reference 4, Acquisition Procedures) that a user will be capable of sending and receiving spacecraft commands and data. For the GSTDN, this is absolutely known because an actual signal from the spacecraft is received by the ground station. Additionally, performance characteristics for communications would be expected to be high (Reference 5) to support the real time transfer of spacecraft data in the "bent pipe" mode (i.e., no storage); therefore it should not be necessary for network operations to directly interact with the user to spacecraft transactions. The disadvantages of high NOCC routine workload and interactions with what would otherwise be a highly transparent communications network were weighed heavily in the negative direction during

this process of routine service. Additionally during this phase of routine service, the characteristics of the network identified above should obviate the need for POCC personnel to interact with the network in other than a bent pipe data communications mode. A change in procedures will be required because of the transition to the through-put philosophy of the network in the TDRSS era. The reduced manning, highly automated systems will not provide the network personnel resources to directly interact with POCCs as is currently done, and procedural changes will likely reflect very limited POCC interaction with STDN ground station personnel regardless of the control methodology selected. Therefore the disadvantages of decentralized control were weighed very lightly (in the negative sense) in this phase of routine service. As a result of these considerations, a matrix control methodology wherein the setup of the network for contract support is centralized and the control of the conduct of user-spacecraft transactions is decentralized was selected.

CONCEPT COMPARISONS

ADVANTAGES

CENTRALIZED

- SINGLE POINT OF ACCOUNTABILITY
- LESS CHANCE OF OPERATOR ERROR
- EASIER MOVEMENT INTO PROBLEM IDENTIFICATION AND RESOLUTION MODE
- MINIMAL IMPACT ON CURRENT PROCEDURES

DECENTRALIZED

- TRANSPARENT USE OF COMMUNICATIONS SERVICE
- EMPHASIZES "NEGATIVE REPORTING" CONCEPT TO FREE NOCC

DISADVANTAGES

- HIGH NOCC ROUTINE WORKLOAD
- HUMAN INTERVENTION IN AN ESSENTIALLY TRANSPARENT COMMUNICATIONS NETWORK
- EXCESSIVE RESPONSIBILITIES ON OPERATIONS PERSONNEL DURING PEAK LOADS OR PROBLEM SITUATIONS

- REQUIRES CHANGE FROM PRESENT PROCEDURES
- POCC (PROJECT) PERSONNEL INTERACTION WITH TDRSS/GSTDN (NETWORK) PERSONNEL CAUSES "LANGUAGE" PROBLEMS

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Principal Control Concept Formulation

INFORMATION FLOWS AND INTERFACES FOR ROUTINE SERVICE

Information flow to assemble the network resources and establish a link with the user spacecraft is focused at the NOCC. At the completion of the acquisition sequence, the focus of information flow may shift to the POCCs/users.

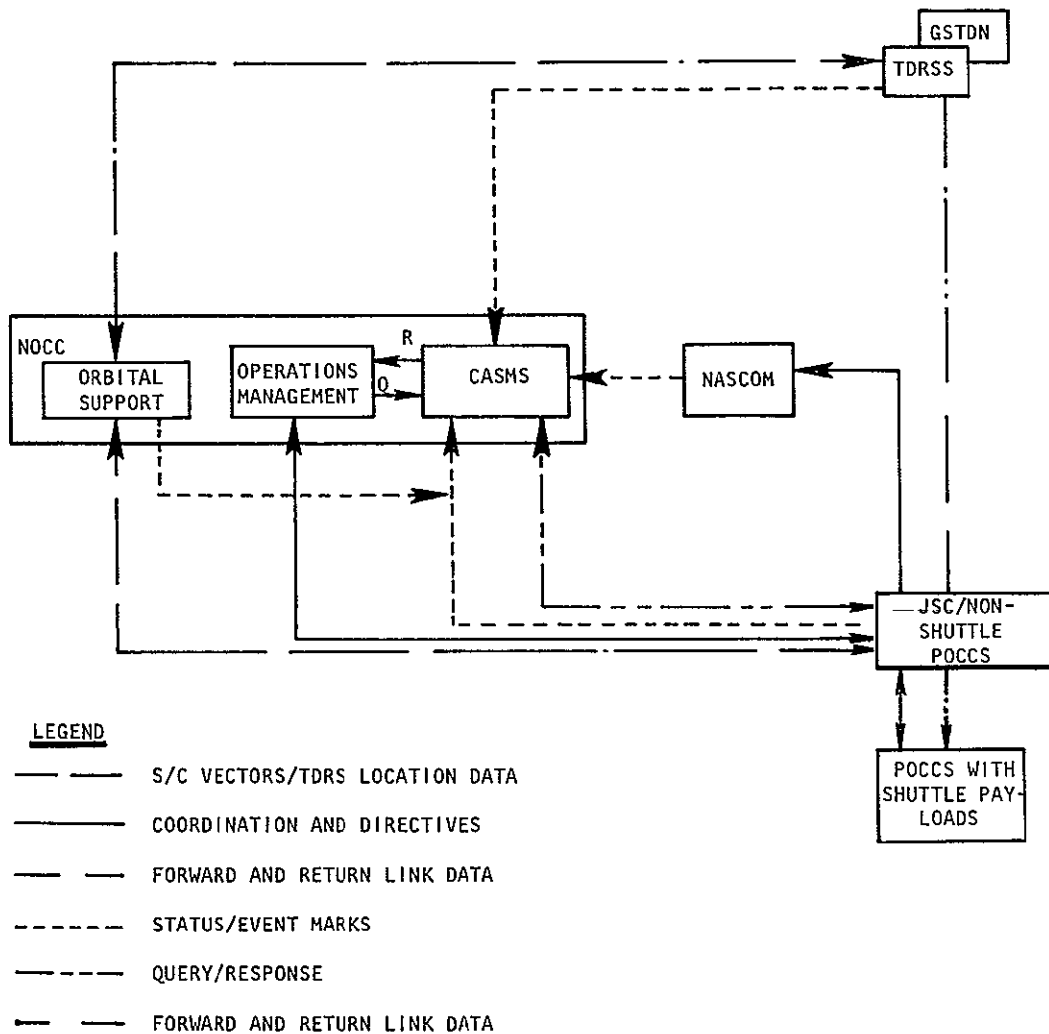
Baseline Loading

The status and event mark interface has the same characteristics as the performance parameter monitoring and event mark interface described for System Integrity. In this case, however, both status and event marks are "level" type signals. At the completion of the acquisition sequence, this interface is used to notify the POCC that spacecraft commands may be initiated and/or that reception of return link information should be in progress. Orbital support data (spacecraft state vectors and predicts) are provided to the TDRSS and GSTDN ground stations via existing digital interfaces (i.e., the 1.5 Mbs, 56 Kbs etc.). POCCs also receive spacecraft orbit support data via low speed automated interfaces. Voice communications between operations management and the elements shown are provided for coordination and/or special directives. The 1.5 Mbs and 56 Kbs communication links between GSFC and STDN ground stations support the flow of routine forward and return link data.

Shuttle Operations

When Shuttle is in orbit, JSC becomes the focal point for associated information flow. Status, event marks and orbital support data are exchanged as if JSC were a POCC. Shuttle return link information will either be passed directly to the POCCs or "cleaned-up" at JSC and relayed to the POCCs.

ROUTINE SERVICE INFORMATION FLOW



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Principal Control Concept Formulation

THE PRINCIPAL CONTROL CONCEPT COMBINES PREFERRED ALTERNATIVES

The Principal Control Concept is a mixture of centralized and matrix methodologies which take maximum advantage of the increased view times, real time data transfer, and standardized systems of the TDRSS era to realize the network goals of transparency, uniformity, flexibility, and efficiency.

Combining Preferred Alternatives

As stated earlier in the report, the analysis segmented the network operations into four tasks that were essentially independent from one another. Doing so allowed the combination of the preferred alternatives from each because there is little impact on the preferred concept of any one on the others. Thus, the principal control concept shown in the figure combines the preferred alternative for each task.

Centralized and Matrix Control

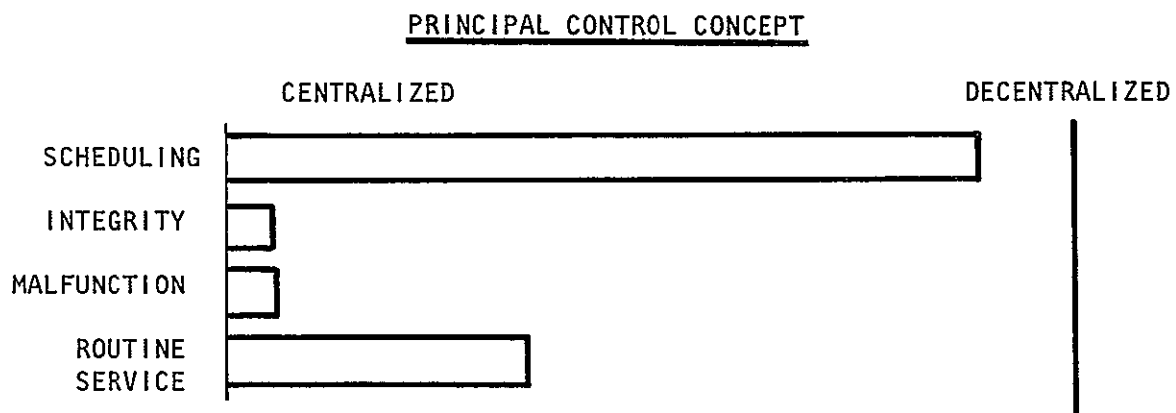
The preferred alternative selected for two of the tasks, Integrity and Malfunction, was a centralized alternative. All of the work, responsibility, and authority were centered in the NOCC. The preferred alternatives for the other two tasks were matrix methodologies.

The matrix methodology for the scheduling task permits the NOCC to vary the degree of centralization/decentralization over a wide range. If needed or desired, the NOCC can run the scheduling function as a completely centralized function with all the work, responsibility, and the authority vested in the NOCC. Or, the work and the responsibility for scheduling can be almost totally decentralized, with the NOCC simply monitoring the activity and maintaining the authority over it. A spectrum of operation conditions between these two bounds can be selected by the NOCC by varying the types of events that can be scheduled by the users, varying the users who can schedule, and varying the lead time for events scheduled by the users.

Routine service also utilizes a matrix methodology, although the degree of decentralization that can be achieved is not as great as that of the scheduling task. The NOCC will always set up the network and then, if it chooses, decentralize control of its use. Like the task of scheduling, the NOCC will always retain authority and can control the amount of decentralization that will be permitted. The NOCC can vary its role from monitoring the use to actually controlling it, and executing this whole task in a centralized manner.

Advantages of the Principal Control Concept

The Principal Control Concept meets the network goals of transparency to the user, uniform operation, flexibility to varying conditions and workloads, and efficient use of people and machines. The concept allows the NOCC to maintain authority at all times, while decentralizing the workload and responsibility when possible. It ensures uniformity of interface operation throughout the spectrum of operations and makes a basic allocation of network responsibility to the NOCC and spacecraft responsibility to the POCC.



- PERMITS THE NOCC TO DECENTRALIZE THE WORKLOAD WHILE RETAINING STDN OPERATIONAL AUTHORITY
- ALLOCATES NETWORK AND SPACECRAFT RESPONSIBILITY TO THE NOCC AND POCC, RESPECTIVELY
- ALLOWS THE NETWORK TO BE HIGHLY TRANSPARENT TO USERS
- PROPERLY DISTRIBUTES NETWORK ACTIVITIES BETWEEN MEN AND MACHINES
- ENSURES UNIFORMITY OF INTERFACE OPERATION THROUGHOUT SPECTRUM OF OPERATIONS

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SENSITIVITY ANALYSIS

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Sensitivity Analysis

SUMMARY OF SENSITIVITY ANALYSIS

The following section presents the sensitivity analysis that was performed on the Principal Control Concept. The impact on the concept was examined for variations in the TDRSS daily loading variations in TDRSS configuration, addition of the Space Shuttle, variations in the GSTDN configuration, and variations in the GSTDN loading.

Organization of Material

The results of the sensitivity analysis that was performed on the Principal Control Concept are presented in the pages that follow. The material is organized in two sections. The first discusses the sensitivity of TDRSS variations, and the second addresses those of the GSTDN. For each section, the report first discusses the loading models and key assumptions that were used, and finally assesses the impact of variations of the assumptions.

Sensitivity of TDRSS Variations

An examination was made of varying both the loading and the configuration of the TDRSS. In both cases, the major impact on the Principal Control Concept was in the operations task of scheduling. As the load increased, the number and the severity of the conflicts increased. The results indicated that a more sophisticated scheduling algorithm would be needed to resolve the conflicts. For all levels of loading, TDRSS Configuration II produced more conflict problems than TDRSS Configuration I.

Space Shuttle Impact

Again, the major impact of adding a Space Shuttle was with the scheduling task. The addition of one Space Shuttle was equivalent to increasing the load by +50%; and the addition of two Space Shuttles was equivalent to increasing the load by +75 to +100%. Both the number and severity of the conflicts increased in both cases.

Variations in GSTDN

When the number of GSTDN sites was increased from the baseline seven to the current fourteen, additional service and back-up service for the Shuttle could be provided. When the number of sites was reduced to less than seven, two impacts were noticed. First, scheduling was once again impacted. Second, the average service that could be provided to the GSTDN users was decreased and continuous dedicated support was seen to suffer numerous interrupts.

ORGANIZATION OF SENSITIVITY ANALYSIS

- MODELING OF TDRSS LOADING REQUIRED ASSUMPTIONS OF PARAMETERS
- DAILY LOADING SUMMARY DISPLAYS LINK LOADING
- PARAMETERIZED MISSION MODEL COMPLETELY CHARACTERIZES GSTDN LOADING
- EXAMINATION OF SENSITIVITY OF PRINCIPAL CONTROL CONCEPT
- LOADING REQUIREMENTS IMPACT SCHEDULING CONTROL METHODOLOGY
- IMPACT OF THE SPACE SHUTTLE IS SIGNIFICANT
- GSTDN ANALYSIS VARIED STATION CONFIGURATION
- GSTDN SENSITIVITY TO SITE AND MISSION MODEL ASSUMPTIONS
- SMALLER GSTDN NETWORK HAS INHERENT OPERATIONAL DEFICIENCIES

Sensitivity Analysis

MODELING OF TDRSS LOADING REQUIRED ASSUMPTIONS OF PARAMETERS

This study's quantitative analysis required the specification of a TDRSS baseline load and associated user spacecraft service characteristics.

Mission Models

The TDRSS Planning Mission Model, Mission Support Summary and STDN Network Directorate Mission Model (References 1, 2 and 3, respectively) were used to the maximum extent possible to define the service characteristics associated with the spacecraft to be supported by TDRSS. However, to obtain application of BDM's quantitative analysis tools, certain assumptions were required to remove ambiguities and fill voids

Baseline Load Definition

The specification of a baseline load was required to allow quantitative impacts of load and concepts variation on the alternative control concepts to be obtained. The spacecraft mission names (or classes) associated with the 4th quarter of 1983 (TDRSS Planning Mission Model) were selected for the baseline load. This year was selected because the widest variety of mission types for a given year are represented, these missions would likely pose a worst-case TDRSS loading, and all spacecraft directly affecting the TDRSS analysis are specified as TDRSS-only compatible.

Orbital Support Assumptions

The daily load offered by each mission to the TDRSS was assumed to be specified as "Minimum Support Required" in Reference 1. Since this load was provided in hours per day, division of this figure by the number of orbits per day (derived from the specified orbit apogee and perigee - Reference 1) yielded the required support time per orbit. For example, in many cases 2.5 hours/day is specified as the minimum support required. This reduces to one 10-minute contact per orbit for a spacecraft at 555 km altitude (e.g., BESS). In addition to length of contact required per orbit, the service characteristics for this contact were needed. These specific characteristics were used as inputs to the Conflict Analyzer, Zero-Order Conflict Resolver and Daily Loading models. The required characteristics were length and frequency of tracking, telemetry/data and command. In some cases, the STDN Networks Directorate Mission Model provided these parameters. For the remaining cases, the TT&C parameters for existing or planned satellites performing similar functions as those in the baseline were used. Since tracking requirements were generally specified in terms of the number of contacts per orbit, one minute of track duration was assumed for base-line analysis. However, the length of track was parametrically varied from

one to eight minutes in this analysis. Additionally, when a mission uses both Multiple Access (MA) and Single Access (SA) service, it was assumed that MA service is basically used for spacecraft telemetry data. Tracking was allocated to SA in these cases because of the suspected limited availability of the MA forward link. Lastly, loading totals on both the forward and return links were necessary to determine channel free time characteristics. Use of the forward link for command during a data dump was assumed to be one minute.

TDRSS MISSION MODELING ASSUMPTIONS

- 4th QUARTER 1982 CHOSEN AS BASELINE LOADING
- SERVICE REQUIREMENTS DERIVED FROM STDN "NETWORK DIRECTORATE MISSION MODEL, 1976 TO 1982," (REFERENCE 3) WHERE AVAILABLE.
- ASSUMED SUPPORT REQUIREMENTS CORRESPOND TO "TYPICAL" REQUIREMENTS EXHIBITED BY PRESENTLY OPERATING OR SCHEDULED SATELLITES OF SAME KIND
- 2.5 HOURS/DAY GIVEN AS "MINIMUM SUPPORT REQUIRED" INDICATES ONE 10-MINUTE CONTACT PER ORBIT
- SA PLAYBACK TAKEN AS GREATER THAN R/T MA SUPPORT (EXCEPT FOR R/T MANEUVER)
- TRACKING PERFORMED USING SA IF AVAILABLE (EXCEPT IF TRACKING IS DONE SIMULTANEOUSLY WITH HEALTH AND STATUS TLM)
- COMMAND TIME FOR DATA DUMP ONLY CONTACT = 1 MINUTE
- COMMAND PLUS TRACKING TIME FOR DATA AND TRACKING CONTACT WAS VARIED FROM ONE TO EIGHT MINUTES

Sensitivity Analysis

DAILY LOADING SUMMARY DISPLAYS LINK LOADING

The Daily Loading Summary contains the orbital and daily support requirements of each mission, and served as a base case from which all subsequent incremental loading changes were derived.

This display provides TDRSS Concept I forward and return link loadings for MA and SA service. The "Total" column matches the "Minimum Support Required" for each satellite (in the baseline) given in the reference. This total is computed by multiplying the number of satellites by the time per contact and the number of orbits per day. Orbits per day are computed from the orbital height specifications in Reference 1. Increases or decreases in loading that were necessary for the Sensitivity Analysis were distributed evenly among the mission classes shown. These load variations were computed by calculating plus and minus 50% of the forward and return MA and SA totals (at the bottom of the summary). An estimate of the mission types that would produce this load, with their baseline characteristics, was made and processed by the Daily Loading Model. Specific satellites were added or subtracted until the best match to the total MA/SA forward and return required loading was produced (normally within one to three percent). Auxiliary satellites were then added to produce the exact loading derived. A similar procedure was followed for TDRSS Concept II. In this way, the total load on each link was raised by the same percentage, and satellites with realistic characteristics were added or subtracted to produce the required loadings.

TDRSS LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
NI	1	0	2	10	9	1 00	30	270	0	0	300
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	22	21	1 00	16	336	0	0	352
HE	1	0	1	22	21	1 00	16	336	0	0	352
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EM	1	0	2	4	3	1 00	24	72	0	0	96
EM	2	0	2	4	3	1 00	0	0	24	72	96
AM	1	0	1	4	3	1 00	15	45	0	0	60
AM	2	0	1	6	5	50	0	0	7	35	42
AM	2	0	1	2	1	2 00	0	0	30	30	60
ER	1	0	3	4	3	1 00	42	126	0	0	168
ER	2	0	3	2	1	2 00	0	0	84	84	168
ER	2	0	3	9	8	2 00	0	0	34	672	756
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
TOTALS							277	1933	320	1765	

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Sensitivity Analysis

PARAMETERIZED MISSION MODEL COMPLETELY CHARACTERIZES GSTDN LOADING

The GSTDN Mission Model used in this analysis is a totally parameterized characterization of expected GSTDN loading in the TDRSS era.

GSTDN TDRSS Era Mission Model

The Mission Model consists of eight total satellites grouped into the categories shown. For reference, the class of satellite intimated by the Mission Model is included with each entry. These missions were chosen to represent the widest diversity possible in mission class, while maintaining a realistic level of system load. Eight total missions were chosen as a baseline to adhere to the assumption that all LEO spacecraft were now TDRSS supported and to facilitate changes of $\pm 50\%$ in total load. Because the GSTDN system loading is, to a large degree, dependent on geography, quantitative loading increases are now totally attributable to increases in number of satellites, in contrast to link loading for the TDRSS. Representative GSTDN supported missions which were the basis for the formulation of this parametric mission model are identified in Appendix C.

GSTDN TDRSS ERA MISSION MODEL

- 4 SYNCHRONOUS MISSIONS
 - 2 CONTINUOUS (POLAR IN NEAR-SYNCHRONOUS ORBIT, ATS)
 - 1 16 HRS/DAY (IUE)
 - 1 8 HRS/DAY (SPHINX)
- 1 LUNAR (CONTINUOUS, LPO)
- 1 HELIOCENTRIC (SMALL NUMBER OF CONTACTS PER DAY, HAE)
- 2 HIGHLY ELLIPTICAL (APPROXIMATELY 5 ORBITS/DAY, MOST TT&C AT PERIGEE, SOME TRACKING AND COMMAND TOWARD APOGEE, ISEE-B AND EE-B)

Sensitivity Analysis

EXAMINATION OF SENSITIVITY OF PRINCIPAL CONTROL CONCEPT

The sensitivity of the Principal Control Concept to variations in TDRSS configurations, mission loading, Shuttle support requirements, and conflict resolution techniques was determined.

The basic measures of performance utilized in the TDRSS sensitivity analysis were number of contacts initially in conflict and distributions of free or unused channel time. This analysis was supported by the Daily Loading Model, Conflict Analyzer and Zero Order Conflict Resolver. The Daily Loading Model identified the daily number of unmanned satellite contacts for the loading variations. This ranged from 250 (-75% of baseline level) to 1200 contacts (+100% of the baseline load). The loads were calculated as previously discussed. The Conflict Analyzer utilized a scheduling algorithm which simulated a totally decentralized scheduling of "specific" requests by assigning each satellite equal priority and randomly scheduling service in each orbit within established constraints. This algorithm and the service constraints are further discussed in Appendix A.

SENSITIVITY ANALYSIS

- TDRSS VARIATIONS -
 - CONCEPT I - EACH TDRS PROVIDES:
 - 1 MA FORWARD CHANNEL
 - 20 MA RETURN CHANNELS
 - 2 SA FORWARD AND RETURN CHANNELS
 - CONCEPT II - EACH TDRS PROVIDES:
 - 3 SA FORWARD AND RETURN CHANNELS
- MISSION LOADING VARIATIONS -
 - +50% OF BASELINE
 - +100% OF BASELINE
 - -75% OF BASELINE
- SHUTTLE SUPPORT REQUIREMENTS
 - 1 OPERATION SPACE SHUTTLE
 - 2 SIMULTANEOUS SPACE SHUTTLES
- CONFLICT RESOLUTION TECHNIQUES
 - INCREMENTAL SHIFTING OF SERVICE
 - SERVICE SWITCHING BETWEEN TDRS'S IN DUAL COVERAGE ZONE

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Sensitivity Analysis

LOADING REQUIREMENTS IMPACT SCHEDULING CONTROL METHODOLOGY

The largest impact of loading variations is on the ASR requirements and the extent to which the scheduling task can assume decentralized characteristics.

Impact On Conflicts

The quantitative results produced by the Conflict Analyzer indicated two distinct classes of conflicts. For loading levels below the baseline, conflicts were characterized by low rates of occurrence and minimal complexity for both TDRSS concepts, the level of complexity being a function of number of satellites involved in, and the duration of, the conflict. Additionally, for TDRSS Concept I, the conflicts at loading levels below baseline (-50% and -75%) were singularly due to SA conflicts for tracking periods of five minutes or less. For longer tracking periods (i.e., eight minutes), a small percentage of conflicts (< 2%) was seen on the MA forward link.

At baseline loads and above (+50% and +100%), conflicts increased in number and complexity. At +50% and +100% loading, the SA conflicts for both Concept I and Concept II exhibited similar traits, numerous conflicts lasted for "long" periods (8-12 minutes at +50%, 14-16 minutes at +100%) and involved as many as four satellites competing for a single SA channel. Additionally, as loads (and track length) increased, MA forward link conflicts increased. Only at +100% loading did MA forward link conflicts contribute more than 20% to the total number of Concept I conflicts. The TDRSS capability of 20 MA return channels was not exceeded for the highest load level investigated (i.e., +100% of the baseline).

Impact On Conflict Resolution

The Zero-Order Conflict Resolver was utilized to measure the effect of a simplistic but automated conflict resolution scheme. As might be expected, excellent results were achieved with this scheme at loading levels below baseline. In fact, all conflicts below -50% of baseline level and 95% of all conflicts at -50% load were resolved utilizing this technique. However, conflict characteristics at loads above baseline limited the number of conflicts which could be reduced utilizing this resolution technique to under 2% for both concepts at +50% of baseline load.

The final consideration addressed the sensitivity to load variations of the question, "what is the probability of providing unscheduled service of duration x minutes in the next hour?" The Conflict Analyzer results are shown. For example, the probability of having at least one time slot of 20 minutes (or greater) where both forward and return SA channels are available is .55 for 100% increase in loading. Since approximately half of the time

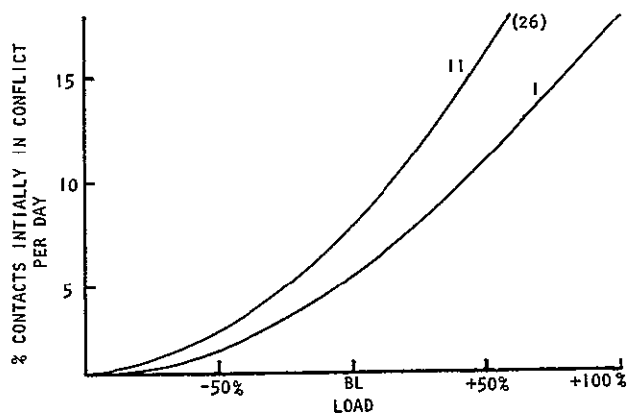
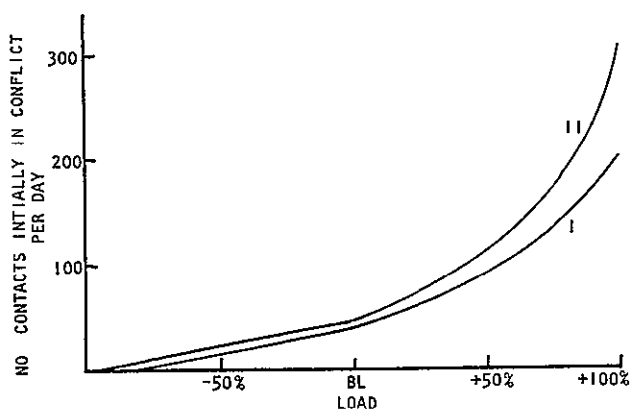
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an interval of this duration will not be available, significant manipulation of the existing schedules would be expected. The conclusions that were drawn from this data are as follows

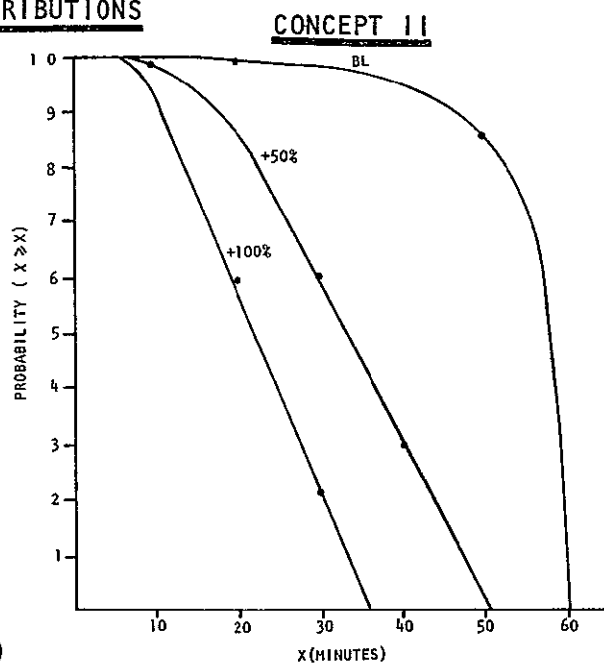
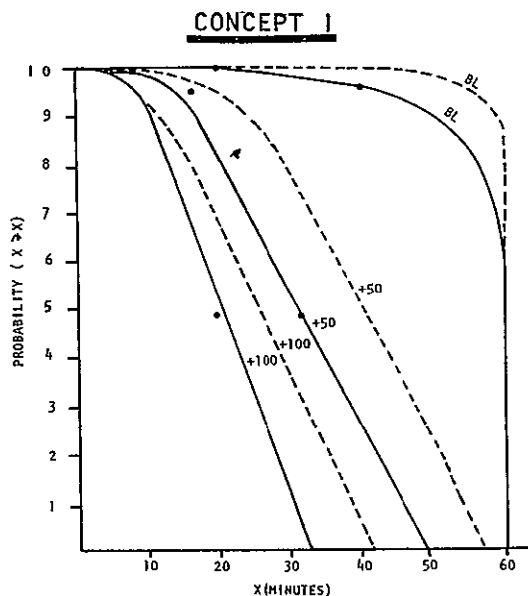
- Sophisticated scheduling algorithms are required for loads of +50% of the baseline and above to manipulate generic requests and thus reduce the number of specific service requests affected (the free time distributions support the feasibility of accomplishing this).
- At the highest loadings investigated, there is a potential requirement to move the scheduling control methodology toward a centralized approach to ensure timely resolution of complex conflicts. Indeed, a satellite-by-satellite priority scheme may be required.

TDRSS LOADING VARIATIONS

CONFLICTS



FREE TIME DISTRIBUTIONS



Sensitivity Analysis

IMPACT OF THE SPACE SHUTTLE IS SIGNIFICANT

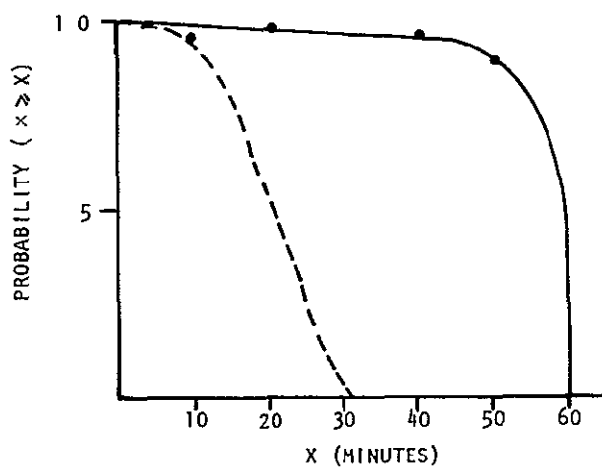
Potential TDRSS Shuttle support produces a significant increase in the number and severity of conflicts and may require a very sophisticated scheduling algorithm to produce a schedule free of conflicts.

In terms of the impact upon the scheduling task control methodology, the addition of the requirement to support one operational Space Shuttle is roughly equivalent to increasing the baseline mission load by 50 percent for Concepts I and II. Supporting two simultaneous Space Shuttles with TDRSS is the equivalent of an increase of 75% and 100% of the baseline load for Concept II and I, respectively. An additional impact is seen in the ability of either TDRSS concept to provide unscheduled service to users without major impact upon the existing schedule. The curves indicate the probability of having at least one SA time slot equal to or greater than X. The solid line represents the case where no shuttle support requirements exist, the dark line represents the case where two Space Shuttles are being supported simultaneously. For example, the probability of having a time slot of 20 minutes or longer (in the next hour) to satisfy a user request for an additional unscheduled 20 minute SA data dump is only about .5. This would imply that half of the time such requests were made, they may not be able to be fulfilled without major manipulation of the existing schedule. Alternatively, when no Space Shuttles are supported by TDRSS, the probability of having at least one 20-minute slot is approximately .99, thus implying almost no impact on the existing schedule.

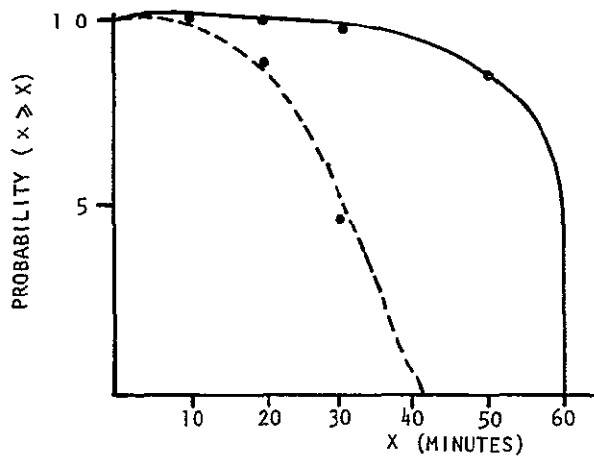
SENSITIVITY TO SPACE SHUTTLE

ESTIMATED DAILY SA CONFLICTS

	CONCEPT 1	CONCEPT 2
NO SHUTTLES	25	42
1 SHUTTLE	101	110
2 SHUTTLES	212	186



ABILITY TO SUPPORT
UNSCHEDULED SA REQUESTS,
CONCEPT 1



ABILITY TO SUPPORT
UNSCHEDULED SA REQUESTS,
CONCEPT 11

LEGEND

— NO SHUTTLES
--- TWO SHUTTLES

Sensitivity Analysis

GSTDN ANALYSIS VARIED STATION CONFIGURATION

The GSTDN sensitivity analysis examined the impact of maintaining the current GSTDN configuration of 14 stations, reducing the GSTDN to less than seven stations, and varying the load by $\pm 50\%$ of the baseline.

14 Station Configuration

In addition to the baseline GSTDN, the assumed 14 station configuration will have a single 9m antenna at HAW, GWM, ACN, AGO, and VAN, and a 12m antenna at QUI. This configuration would represent the network capabilities were the planned closing of these stations by the early 1980s postponed or cancelled.

Less Than 7 Station Configuration

The minimal set of stations that could be retained for the STDN is ORR, GDS, and MAD. Planners would always keep these stations in the network because of their favorable geographic spacing (approximately 120 degrees in longitude) and a favorable distribution about the equator. ETC (9m) should remain as a test center and also because of its ability to serve synchronous satellites in the Atlantic region. MLA and BDA will always be necessary for launch and early orbit support. The possible losses to the baseline system are then seen as ULA (9m), ROS (9 and 26m), or ULA and ROS.

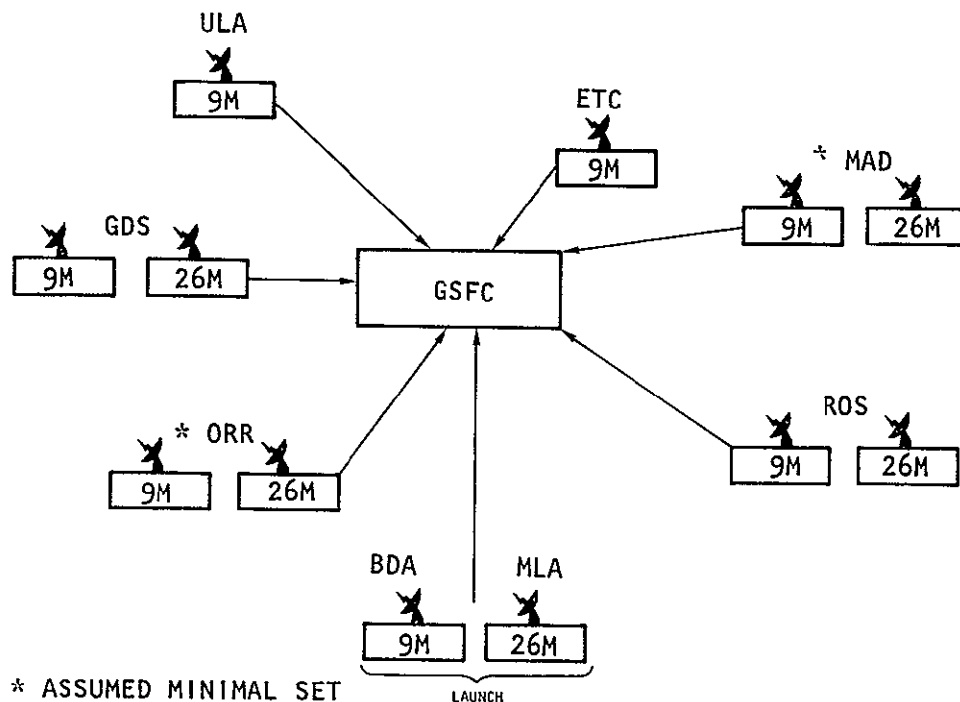
$\pm 50\%$ Loading

The addition and subtraction of four missions to the baseline model were chosen to represent a 50% increase and decrease in loading as seen by the sites themselves. The four missions were chosen from all mission classes and their effects distributed among postulated antenna usage to analyze any changes in network operations that might result.

SENSITIVITY ANALYSIS GSTDN VARIATIONS

- 14 STATIONS - PLANNED 1978-1979 CONFIGURATION PRESENTED IN NETWORK SUPPORT CAPABILITY PLAN, FEBRUARY 1976
- LESS THAN 7 STATIONS - REMOVE ULA
REMOVE ROS
REMOVE ULA AND ROS
- +50% LOAD - 12 TOTAL MISSIONS
TO BASELINE ADD 2 SYNCHRONOUS
1 HELIOCENTRIC
1 ELLIPTICAL
- -50% LOAD - 4 TOTAL MISSIONS
TO BASELINE SUBTRACT 2 SYNCHRONOUS
1 HELIOCENTRIC
1 ELLIPTICAL

GSTDN SITE ASSUMPTIONS



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Sensitivity Analysis

GSTDN SENSITIVITY TO SITE AND MISSION MODEL ASSUMPTIONS

The GSTDN sensitivity analysis required basic assumptions concerning the mission loading as well as the location, number, and size of available antennas.

Basis For Analysis Mission Models

The GSTDN related sensitivity analysis required analyses of required assumptions concerning station configurations and the GSTDN Mission Model.

Mission Assumptions

The loading to be supported by the GSTDN is assumed to be that of the post-transition period when all carryover support of low earth orbit (LEO) missions has ended. GSTDN supported satellites in this period will be either synchronous, in near synchronous altitude orbits, heliocentric, lunar, or highly elliptical. These spacecraft (except near earth passes for the elliptical spacecraft) will have "longer" GSTDN view times (i.e., hours instead of minutes), be visible on most occasions by more than one GSTDN site, and be restricted in service duration only by the availability of an appropriate size antenna (26m or 9m). Little information regarding the number, specific type and service requirements for GSTDN supported TDRSS era spacecraft was available. All support requirements, therefore, were assumed to be analogous to presently planned spacecraft projects. Included in the assumptions are "dedicated" antennas for synchronous satellite support and prioritized antenna allocations for orbital maneuvers of elliptical spacecraft, such as AE or OSO.

The information contained in Appendix C identifies the basis for the assumed support requirements. To accomplish the GSTDN sensitivity analysis, the specific number and type of each mission supported in the TDRSS era were also required. To fill the information void, missions were categorized. The number and type of satellites in each mission class were derived from trends identified in the TDRSS Planning Mission Model (Reference 1). A parameterized Mission Model was, consequently, derived which can be compared to available GSTDN resources to examine the effects on the Principal Control Concept of changes of loading and number of sites.

Baseline Ground Sites Assumptions

The forecasted set of ground sites for the TDRSS era is ULA, ORR, MAD, ROS, GDS, MLA, BDA, and ETC. Their antenna capabilities are as shown. It is assumed that each site will have DDPS/TDPS/SCE equipment and maintain real time or near real time data transfer capability.

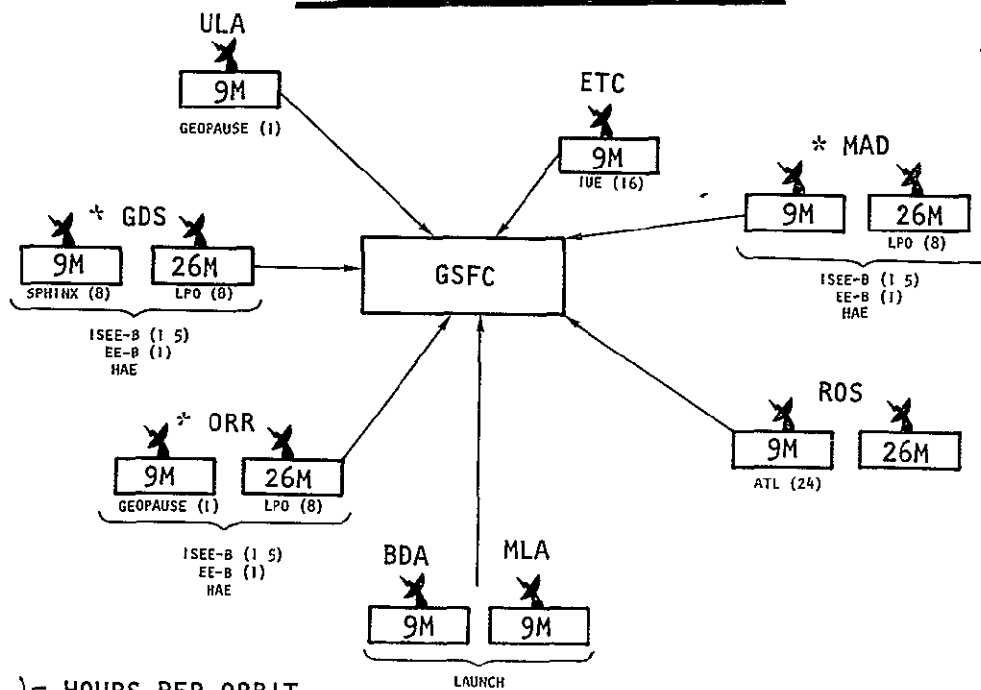
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When reducing the number of ground sites to less than the fundamental set of Five for orbital support, two for launch (MLA, BDA) and one for training (ETC), it was assumed that GDS, MAD, and ORR would always be a part of the GSTDN, as well as ETC and the launch support stations. In short, analysis was conducted on the effects of removing ULA, ROS, and ULA and ROS on the Principal Control Concept. When 14 stations were considered, the planned 1978-1979 station configuration from the Network Support Capability Plan was used.

GSTDN MISSION MODEL ASSUMPTIONS

- ALL SATELLITES EITHER
 - SYNCHRONOUS
 - NEAR SYNCHRONOUS CIRCULAR ORBIT
 - LUNAR
 - HELIOCENTRIC
 - ELLIPTICAL (MANY EARTH RADII AT APOGEE)
- TOTAL PARAMETERIZATION OF
 - NUMBER OF SATELLITES
 - TYPE OF SATELLITES
 - SUPPORT REQUIREMENTS FOR KNOWN MISSIONS

GSTDN BASELINE LOADING SCENERIO



Sensitivity Analysis

SMALLER GSTDN NETWORK HAS INHERENT OPERATIONAL DEFICIENCIES

The Principal Control Concept is unaffected by the use of a 14-station GSTDN, while less than 7 stations will produce increases in interrupts of dedicated service to synchronous satellites and also suggests the use of a priority scheme for scheduling.

14-Station Configuration

The planned 1978-1979 GSTDN configuration could supply service to the baseline mission model with no effect on the Principal Control Concept. This configuration would provide added emergency support and Shuttle back-up because of its increased geographical diversity

Less Than 7-Station Configuration

Increases in interrupts to dedicated synchronous support will become more frequent if ULA, ROS, or both, are moved from the network. This will occur when the loss of ULA places GEOPAUSE and SPHINX in conflict on GDS 9m antenna, or when the shift of the Atlantic synchronous satellite to MAD causes conflict on the 9m link with an elliptical satellite at perigee. Backup capabilities are also diminished for handling unscheduled downtimes and emergency situations requiring geographically diverse facilities.

±50% Loading

The primary impact of a 50% increase in loading on the Principal Control Concept is in the area of scheduling. Coordination of the scheduling of the 9m and 26m antennas will be accomplished through the efforts of the NOCC, the use of a priority scheme, or resolution by projects. Because the time available for system maintenance will decrease, NOCC coordination will again play a larger role in the scheduling function. There will be no effect on the Principal Control Concept for a 50% decrease in load.

GSTDN SENSITIVITY ANALYSIS RESULTS

- MAJOR IMPACT OF GSTDN VARIATIONS IS ON SCHEDULING
- INCREASED LOADING TENDS TO REQUIRE A SATELLITE-BY-SATELLITE PRIORITY SYSTEM FOR SEVEN OR LESS GSTDN STATIONS
- NOCC WILL BE REQUIRED TO SPECIFY SYNCHRONOUS INTERRUPTS FOR INCREASED LOADING AND/OR LESS THAN SEVEN GSTDN STATIONS
- FOURTEEN STATIONS PROVIDE INCREASED CAPABILITY TO SUPPORT SHUTTLE
- BACKUP CAPABILITIES FOR UNSCHEDULED DOWNTIMES AND EMERGENCIES DECREASE FOR LESS THAN SEVEN STATIONS

**PHASE II
ANALYSIS RESULTS**

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INTRODUCTION

III-3

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Introduction

ORGANIZATION OF PHASE II ANALYSIS

The results of the Phase II analyses are presented in three major sections; Control Concept Refinement, Human Factors Considerations and Cost Analysis. Appendices provide detailed information, supporting conclusions and recommendations, where necessary.

Control Concept Refinement

This section of the report refines the basic characterization of the operations control concept alternatives identified in Phase I. In the concept alternatives, the NOCC was characterized by Operations Management and the ASR and CASMS hardware/software systems. It was implicit in the Phase I analysis that Operations Management was the relationship of personnel and tasks that in reality implemented the control concept. The ASR and CASMS were the tools which assisted in the implementation of control. Additionally, a set of information flows were identified which served to characterize the control center, user, STDN element interfaces. The refinement of these characteristics is presented in three subsections which address the Automatic Scheduling Routine (ASR), Control and Status Monitoring System (CASMS) and Operations Management. In the refinement of Operations Management, three salient human factors subject areas are addressed: major skill levels needed, task capabilities of the different skill levels, and tool requirements for each skill level.

Inclusion of these areas in this section allows the characteristics of Operations Management to be refined to the level where NOCC staffing can be identified and its basis demonstrated in a logical flow. Additionally, the impacts of loading and control concept variations upon the Principal Control Concept can be presented in terms of personnel as well as hardware/software changes.

Human Factors Considerations

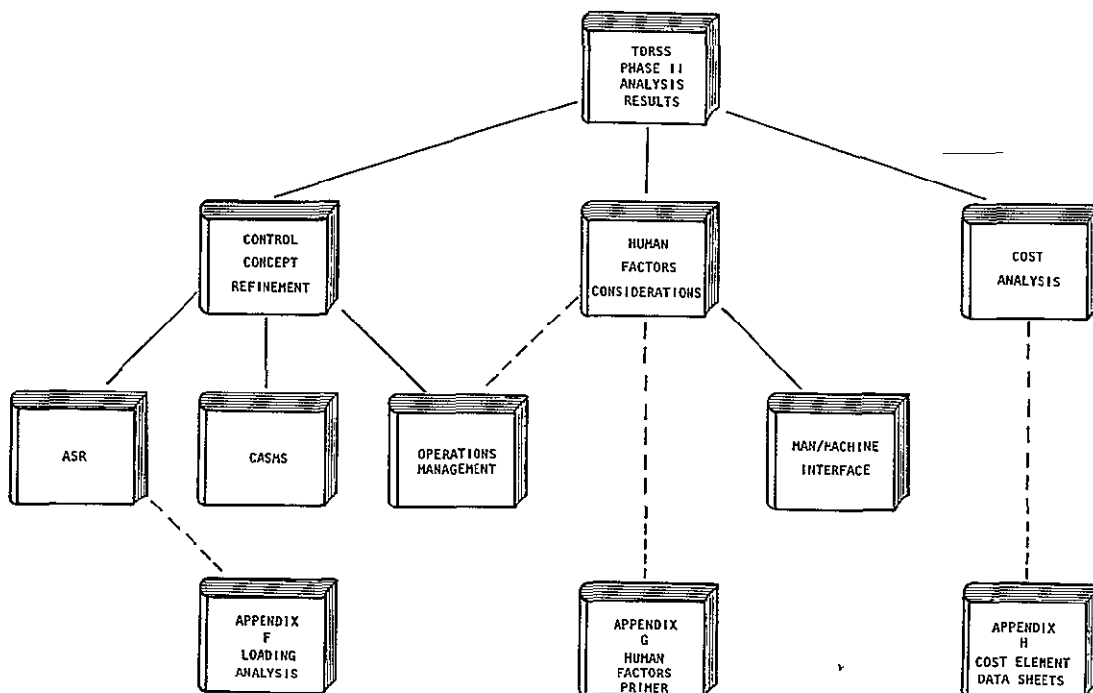
Specific topics relating to the STDN Control Center man/machine interface are developed in this portion of the report. These topics include working space requirements, CRT display character parameters, personnel selection and training, color versus monochrome display trade-offs and the man/machine interface. These topics were selected because the parameters which affect the analysis are not directly impacted by control center configuration, location and structure. Therefore, although the selected control concept recommends a specific configuration, location and structure for the NOCC, these analysis results are equally applicable to other control center configurations.

Supplementing the specific topics treated within the body of the report, is a specialized human factors primer which treats the general area of working conditions. This primer presents guidelines and methodologies for determining and implementing working condition changes motivated by human factors considerations.

Cost Analysis

For the various control concepts developed in Phase I and the refinements reported herein, Rough Order of Magnitude (ROM) cost estimates are provided for major control system components. Cost Summaries are provided in the report and supported with detailed cost data sheets in Appendix H. Cost comparisons are made between the Principal Control Concept and alternatives synthesized in Phase I.

ORGANIZATION OF THE TDRSS PHASE II ANALYSIS REPORT



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CONTROL CONCEPT REFINEMENT

—
ASR

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Control Concept Refinement - ASR

AUTOMATED SCHEDULING ROUTINE - A MULTI-CAPABLE NETWORK MANAGEMENT TOOL

Phase I analysis identified the automated scheduling routine as a powerful computer algorithm that not only produces the network schedule, but also serves as an interactive network tool used for planning and conflict resolution.

Introduction

The Phase I analysis described a set of network control concepts for STDN operations in the TDRSS era. Basic to each of these was the Automatic Scheduling Routine (ASR). Below is a summary of material from the Phase I report, describing the functions and desired capabilities of the ASR in its role of controlling the allocation of network resources. The remainder of this section is dedicated to refinement of the ideas presented in the Phase I report as they apply to the ASR

Provision of Service Ordering

To take advantage of long TDRSS view times and large amounts of free time, service requests were assumed to be one of the following forms: generic, specific or quasi-generic. Generic requests are those which must be periodically scheduled, but the time at which the event occurs is not critical within specified rules. Specific requests represent the other end of the request spectrum. These events require scheduling at the precise time requested. Quasi-generic requests are specific requests with increments about their initiation times. For example, a request for return link support of a data dump may specify a desired start time plus or minus "X" minutes. Therefore, a time variant provision of the service ordering scheme can be adopted as part of the scheduling approach. In this scheme all satellites are assumed to have equal weighting when requesting use of STDN resources. However, specific requests would always be scheduled first, quasi-generic second, and generic last. Also, the request type, and hence weighting, could change as a function of time. For example, periodic preventive maintenance (PM) could be considered initially as generic requests but as the time since the last PM increases, the next required PM activity assumes a more "specific" nature.

Identification of Scheduling Alternatives/Interactive Capability

There will exist situations when the algorithms designed to supply conflict free schedules may not be able to do so without violating built-in program constraints. This may occur during periods of heavy loading or when priority considerations cannot be resolved. In keeping with the goals of transparency and flexibility, it is desirable for the system to generate possible alternatives for service at these times. If a decentralized mode

is selected for the ASR, the users may then be given available choices that are compatible with the scheduling algorithm which are close to their original requests. If a centralized mode were selected, this information would be given to the NOCC. In the same way, a user could make numerous requests for the program, be informed of the impact that each would generate and select from among them. This flexibility of the interactive capability gives the NOCC the ability to minimize its routine contact with the users and gives the users the information needed to request schedule changes.

Balance Between Forecasting and Near-Term Scheduling

To facilitate project support planning, schedules must be produced and service "guaranteed," within limits, with sufficient advance notice. This implies that users can define their needs far enough into the future with enough confidence for them to be entered into the ASR. For the orderly functioning of the ASR, the terms "define their needs" and "far enough into the future" must be carefully examined and judicious choices made for their specification.

The network must also be responsive to the needs of users which arrive unexpectedly or within a short period before the support is needed. Requirements for supplementary tracking contracts or an orbital maneuver needed to observe some phenomenon (e.g., solar flares for OSO) may occur during the execution of "guaranteed" service, and the ASR should be capable of incorporating these requests in real time with a minimum impact on the remainder of the users. Again, a thorough analysis of the problem must be made before a "cut-off" point is chosen, after which all inputs are considered "interrupts" rather than scheduled entries. An alternative to this scheme is a constantly updated schedule with no deadlines at all. The important differences seen between the ASR and present methods are the potential reduction in lead-times from days to hours, and the automated real time rescheduling or presentation of alternatives which permit POCCs to perform the work and assume the responsibility for their own scheduling.

NOCC Authority Over Matrix Control

The ASR is designed to support a matrix control concept. As such, the ASR permits the scheduling function to be almost entirely decentralized, with all interfaces being between the ASR and the users. In this configuration the NOCC would monitor the operation of the ASR. However, the ASR also can be configured to be totally centralized. In this case the users still enter requests directly to the ASR, but no scheduling changes are made without NOCC approval. Varying degrees of centralization/decentralization can be achieved by the NOCC by modifying the ASR to decentralize types of events, specific users, events with certain lead times, etc.

Control Concept Refinement - ASR

A SOPHISTICATED SCHEDULE PROCESSOR IS AN ESSENTIAL REQUIREMENT

To ensure the timely resolution of complex conflicts, while concurrently providing efficient management of the projected system loads and the requisite planning capability, the ASR concept requires a sophisticated scheduling processor.

Scheduling Algorithms

A scheduling algorithm is a highly structured process in logic. Requests for job execution are input, and the process, at a minimum, analyzes the requests to verify feasibility and identifies any conflicts that may exist. If no conflicts exist, a schedule queue is established and documented in the data base. When conflicts are discovered, the process will attempt to resolve the conflicts or at least provide feasible alternatives to users.

The initial establishment of a schedule and the resolution of conflicts can be performed at various levels of algorithm sophistication. On the most basic level, an algorithm may produce a schedule which is simply feasible. In such a case, the process terminates when any schedule is obtained which can be executed with available resources in the allotted time. However, greater system efficiency can often be realized if the process is designed with cognizance of the schedule request behavior. In addition, special effects or system objectives may be obtained with the use of even more sophisticated algorithms.

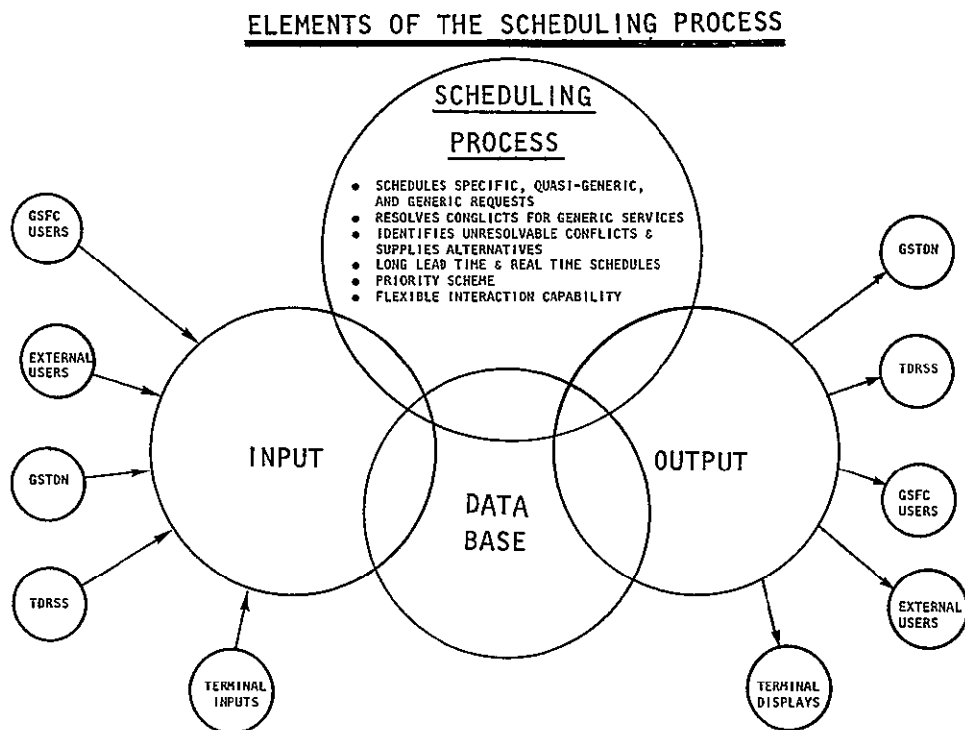
Scheduling in the Phase I Model

In the Phase I analysis, a simple model of STDN scheduling activity was studied using 1983 projected network utilization as baseline load. In that study the schedule requests to the ASR could be viewed as specific requests submitted by the users. Results from the Conflict Analyzer indicated that only about five percent of the initial requests were in conflict. It was also determined that a very high percentage of the requests for service initially in conflict could be honored when the requests were allowed to be moved by the zero-order conflict receiver a given number of minutes from their originally requested time. However, when loads were increased, the capability of the scheduler to grant requests dropped very rapidly. This phenomenon was particularly noticeable when the shuttle was introduced into the network load. At the conclusion of the Phase I analysis, two major requirements were identified for the ASR: 1) capability for centralized control to ensure timely resolution of complex conflicts during high load periods, and 2) the use of a more sophisticated scheduling algorithm to manipulate generic requests under heavy system loads.

In response to the ASR requirements identified in the first phase of the research, the initial step of the continuing research was directed towards an investigation of the nature of STDN scheduling problem within the state of the art. The attributes of manual and automated scheduling mechanisms were compared and based on accepted mission models, requirements were reassessed in more detail and recommendations for algorithms were made

The results of the research are presented in the following pages of this report. The information had been categorized into three general sections addressing first the general case, then STDN. Following a summary of the finding, the sections are presented in the following order:

- 1) The nature of the scheduling problem,
- 2) Categories of scheduling problems and configurations, and
- 3) Recommendations and rationale.



Control Concept Refinement - ASR

PHASE II FINDINGS ON THE AUTOMATIC SCHEDULING ROUTINE

As a result of the Phase II analysis, recommendations are made for the implementation of an automatic scheduling routine to handle scheduling for STDN.

Feasibility of ASR

Implementation of an automatic scheduling routine was shown to be a feasible consideration in Phase I. In Phase II more justification for the feasibility of an ASR was provided as well as recommendations for the implementation of such a system. The Mission Model (Reference 1) indicates the requirement for 1500 to 2000 hours of support to be provided on STDN resources (Appendix F). Added to this scheduling load, the requirements to provide near- and far-term scheduling, interactive and trial scheduling, and data base query capabilities were sufficient to justify automation.

Cost Considerations

The cost of an automated system was also found to be an incentive to implement an ASR. It was estimated that a savings in manpower of up to 67% could be effected, yielding a savings of nearly \$5 million in manpower costs. Hardware and software development costs were estimated to range from \$500K to \$800K.

Algorithms

A fairly sophisticated algorithm will be needed for the ASR, but initially a multiple pass feasibility search would be used and the capability to add loading rules as subroutines would be provided.

Further investigations to find algorithms to solve the overall STDN scheduling problem should focus on research on the N/2 Job Shop and Branch and Bound type algorithms. In addition, STDN should be further analyzed to identify systems to which existing scheduling algorithms might be applied.

Hardware

Finally, dedicated hardware was selected for ASR implementation in order to ensure that the NOCC scheduling operation would always have highest priority to access the ASR if centralized control was necessary. Although existing GSFC equipment could potentially support this application, use of a dedicated mini-computer of some sophistication would, in the long run, avoid the conflicts which are part of operational reality in a large computing system.

PHASE II FINDINGS - SCHEDULING

- PROJECTED WORKLOADS AND DESIRED PERFORMANCE CAPABILITIES JUSTIFY ASR
- COST OF ASR IS AN INCENTIVE
 - \$5 MILLION SAVINGS IN MANPOWER COSTS
 - COMBINED ASR HARDWARE/SOFTWARE DEVELOPMENT COSTS ESTIMATED AT \$500K - \$800K
- SOPHISTICATED ALGORITHM REQUIRED
 - MULTIPLE PASS FEASIBILITY
 - HEURISTIC LOADING RULES
 - APPLICATION OF EXISTING OPTIMIZATION ALGORITHMS TO SPECIFIC SUBSYSTEMS
- PURSUE RESEARCH OF N/2 JOB SHOP, BRANCH AND BOUND ALGORITHMS
- UTILIZE DEDICATED HARDWARE

Control Concept Refinement - ASR

INTRODUCTION TO SCHEDULING THEORY

Problems of sequencing activities arise in even the most mundane settings when operations must be ordered before they can be executed. In discussing the methodologies involved in scheduling theory, distinctions will be observed between schemes for describing schedules, scheduling techniques aimed at particular operational goals, and actual methods for generating schedules.

Broad Range of Problems

Whenever a choice exists as to the order and way in which a number of tasks might be accomplished, there is a potential scheduling problem. Scheduling "problems obviously get solved, however, most of these problems are solved quite casually or automatically without explicit recognition that a problem ever existed, much less that a solution was obtained." (Reference 19) The study of scheduling has progressed significantly in the last 20 years, but even in 1973 R V Oakford, speaking of school scheduling, saw "the area of interactive scheduling. .[as]. almost wide open." (Reference 20)

Views of Scheduling Problems

Scheduling problems can be viewed from many different angles. A variety of mathematical or analytic tools form the theoretical basis for studying schedules, and the choice of analytic technique depends upon the setting of the particular problem. In addition, before any significant progress toward solving a particular problem can be made, the problem must first be clearly stated. Then the operational objectives of the system must be determined. Finally, the method to be used for producing the schedule must be chosen. Different aspects of scheduling theory apply to each of these areas. The ensuing discussion implicitly distinguishes three aspects of scheduling theory. analytic frameworks, scheduling objectives, and schedule generating techniques.

Theoretical Basis

Three analytic techniques are used in the study of scheduling problems. algebraic, probabilistic, and Monte Carlo simulation. Algebraic techniques involve explicit calculations and focus on fixed data or values such as average or maximum flow time for a given schedule. Such techniques are applied to scheduling situations where everything that is to be accomplished, resources to be allocated, tasks to be performed, etc., are known and deterministic. In other cases, however, conditions change with time such as the number of things available to be done or the resources, machines, manpower, materials available to do the required work. Often the behavior of the demand or the resource availability can only be predicted as trends in time. In such cases probabilistic studies are often used to determine

what to do next or what resource to apply. The calculations involve stochastic values and the results, therefore, involve probabilities or confidence ranges. In still other cases, the focus of the study may be narrower, involving a particular set of resources and operations. If the system of resources and operations will be functioning continuously, computer simulations are effective tools in studying and comparing schedules. The system model is allowed to run, and its performance is assessed from output data.

Analytic Frameworks

Analytic Frameworks are the languages or words in which scheduling problems are posed. Most notable among these is the job shop. Terminology used in this process is derived from an idealized manufacturing situation, viewing things to be done as jobs and resources to be applied to the jobs as machines. The job shop process will be more fully discussed on page III-30.

Scheduling Objectives

Scheduling with particular objectives in mind may be done to enhance some aspect of a system's performance. Scheduling against due dates is an example of such motivation. Particular objective functions are used to aid choosing between alternative feasible schedules. Objective functions as they apply to STDN will be treated on page III-24.

Schedule Generating Techniques

Finally the actual processes for creating a schedule for the activities of an organization or system may be studied. These vary from the simplest rostering techniques which involve simply searching along for the first available time slot in which to schedule an activity to the most sophisticated computer run algorithms which provide schedules optimized with respect to some goal. On III-26, a better understanding of the range of schedule generating techniques and a comparison of their various attributes will be provided.

These distinctions underlie the discussion in the subsequent section of this report. After the scope of these various areas has been described, recommendations for fulfilling STDN's needs in preparation for the TDRSS era are made.

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Control Concept Refinement - ASR

GENERAL CHARACTERISTICS OF SCHEDULING PROBLEMS

A scheduling problem exists whenever a number of jobs must be completed with the use of a limited number of resources within specified time constraints.

Information Types

Any specific scheduling problem is described by four types of information

- 1) The nature and number of jobs and associated operations to be processed,
- 2) The number or quantity of available resources,
- 3) Exogenous constraints or disciplines that restrict the manner in which scheduling assignments can be made, and
- 4) The measure of effectiveness or generic criteria by which the formulated schedules are evaluated.

Resource Considerations

Depending on the nature of a job, the limiting resources may include manpower, money, supply of materials, and machines. The one resource which is common to most scheduling problems is time. A scheduler is most often faced with deadlines or at least must work within "as-soon-as-possible" time constraints.

Operations Required

Scheduling problems may be further complicated by the added dimension of the number of operations per job. This dimension may compound the number of steps a job must be processed through before completion or may specify a sequence of steps which affect decreases in the system flexibility causing the scheduling process to become more difficult.

Constraints

Exogenous constraints limit the feasibility of scheduled jobs. These constraints would include any factors which could prohibit the processing of a job for reasons other than resource availability, such as eclipse conditions for a TDRS.

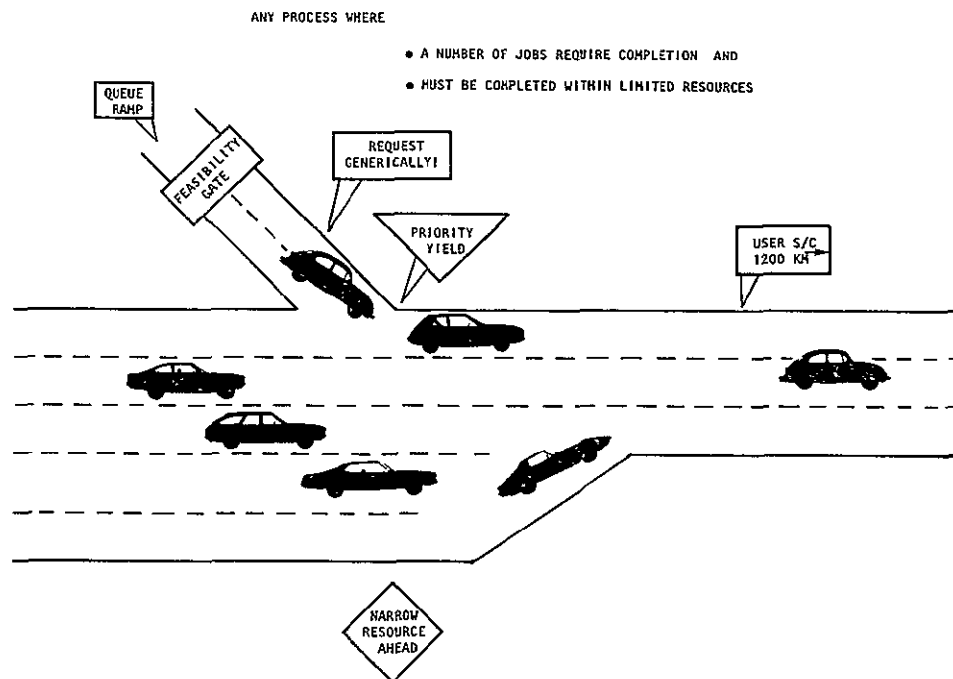
Criteria

The criteria by which schedules are evaluated are often unique to the particular problem. These criteria are used to ensure that the scheduling objectives are attained. Such objectives range from simply producing an adequate or feasible schedule, to providing very efficient or optimal schedules. It should be noted that uniqueness in scheduling objectives has thwarted attempts to find general solutions to many large scheduling problems.

Representation

The figure illustrates the type of problem which has just been described. The roadway represents the resources over which the cars, representing jobs, must pass to reach their desired destination. Some jobs are already on the road, scheduled, others are trying to enter it, requesting placement in schedule queues. Cars enter the highway, schedule requests are granted, with cognizance of the narrowing road ahead, limited resources.

DEFINITION : SCHEDULING PROBLEM



Control Concept Refinement - ASR

THE STDN SCHEDULING PROBLEM

The STDN scheduling problem results from attempting to fulfill user request for satellite communication services with a limited quantity of equipment resources within major network components.

Salient Problem Elements

The driving element of the problem is the request for user operations as shown on the left hand side of figure. These operations include routine communications, simulations and tests, launch and recovery, spacecraft emergencies, and other similar operations. Any ground station may be considered its own user when requesting maintenance operations.

Each of these operations is composed of one or more fundamental STDN service functions. For example, routine communications are, in fact, a series of telemetry, tracking, and command system functions. These are the service functions that are scheduled by the ASR, i.e., they require the allocation of resources.

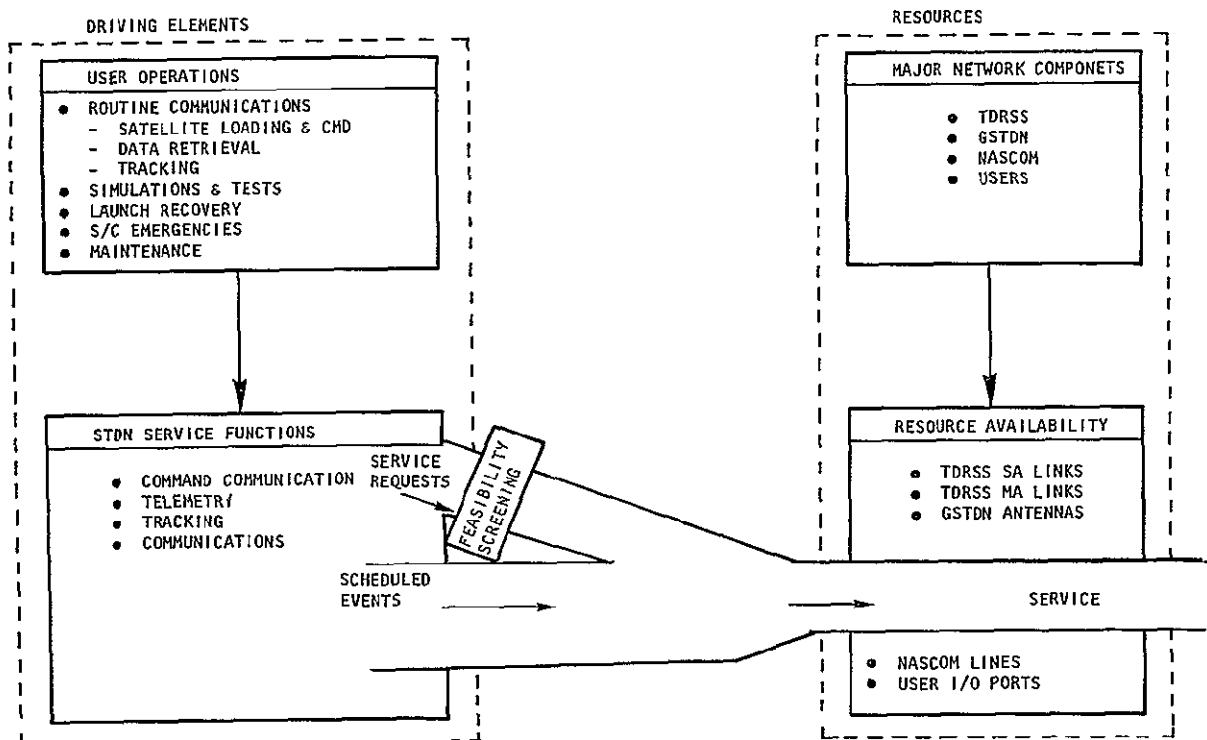
Allocation of Resources

A schedule of the allocation of STDN resources is produced in response to the user requests. The major elements which must be scheduled are TDRSS, GSTDN, NASCOM, and user facilities. These segments of the network control the various pieces of equipment necessary to complete a link, either forward or return, with a user satellite. The quantity and characteristics of this equipment impose constraints on the service requests STDN can possibly grant. For example, there are only six TDRSS single-access (SA) and 23 multiple-access (MA) channels including the space; and NASCOM lines have fixed data rate and frequency capabilities.

The scheduling of a user's request for service entails the coordinated scheduling or dedication of compatible equipment from the network subsystems indicated.

Even though some STDN equipment may be available for the support of a given spacecraft at a particular time, exogenous constraints may still render a service request infeasible. Such constraints include configurations, for SA or MA, TDRSS or GSTDN support, frequencies, data rates, and predicts such as AOS, LOS, and sun angles. Part of any STDN scheduling system is feasibility screening based on these technical and physical considerations. This information will be maintained in the data base for the ASR to facilitate verification of request feasibility before the request is scheduled.

THE STDN SCHEDULING PROBLEM



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Control Concept Refinement - ASR

SATISFACTION OF USER DEMANDS ON STDN DEPENDENT LARGELY ON COOPERATION

The limited resources of STDN can be severely taxed by user demands. User cooperation and a mutual recognition and appreciation of priorities will be prime requisites to full mission accomplishment.

Interrelationships

The figure illustrates the interrelationship which exists among users. Simply stated, when a user requests allocation of resources for his own purpose, he has further constrained the resources available to the remaining users. When loads peak (concentration of jobs within a finite time interval), users may be denied service due to the lack of available resources. However, mutual cooperation on the part of users can minimize the level of peak loading. If, as suggested in the Phase I report all users have an interactive capability, they can be aware of busy periods and select alternative times. For example, User #1 (POCC #1) in the diagram might represent the Shuttle which captures all of the TDRS-West SA capability. Other users coming into the system requiring SA links, cognizant of existing loads, would make requests for periods of times when loads are lighter but which still satisfy their requirements.

Such a system would be far different from the scheduling process used by STDN today. However, in light of the potential for scheduling problems the equitable allocation of resources may be incentive enough to win user cooperation.

System Flexibility

Equitable distribution of resources implies the allocation of communication links to users based on respective needs. This can be accomplished only when a sufficient degree of system flexibility, facilitated by user cooperation, is present.

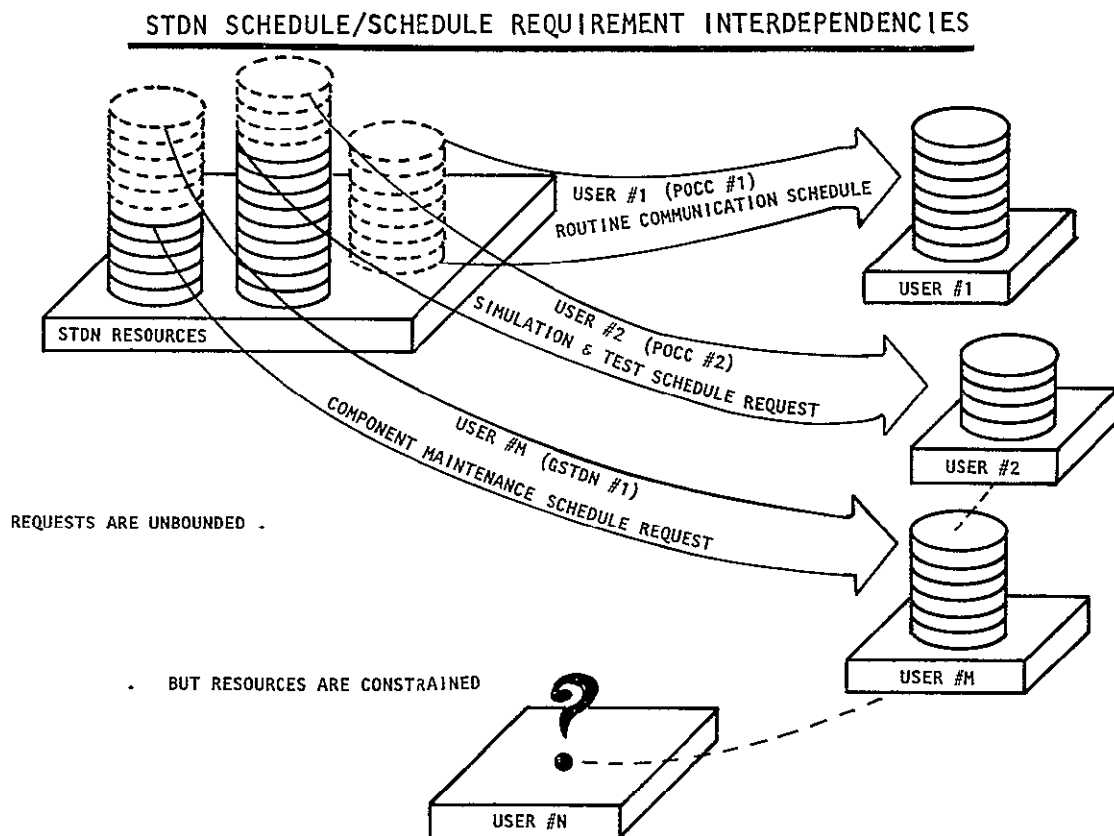
Several other user benefits are to be derived through system flexibility. When peak loads or busy periods are eased, the probability of providing unscheduled or emergency service without causing major perturbations in the existing schedule is significantly increased. Conversely, the probability of a scheduled event being charged or "bumped" by a high priority event is minimized.

System flexibility can be further increased by avoiding inflexible schedule requests whenever possible. Specific requests severely constrain the capability of the schedule processor and may minimize overall system capacity by denying even a complicated scheduling processor the ability

to adjust the timing of scheduled events to resolve conflicts. On the other hand, generic requests permit the processor to plan events in light of request behavior, minimizing loads during busy periods and maximizing the probability of granting random requests

Implications

User cooperation, therefore, will provide sufficient flexibility to allow STDN to employ and benefit from scheduling algorithms of higher levels of sophistication.



Control Concept Refinement - ASR

THE SEQUENCING OF STDN RESOURCE ALLOCATION IS SITUATION DEPENDENT

Within a flexible system, a number of feasible schedules may exist, one or more of which may be deemed more desirable based on specific criteria.

Gantt Chart

The figure presented here is a Gantt Chart which illustrates an example of a feasible schedule of STDN communication links. Each line of the chart represents a link, and the rectangles, both solid and dashed, represent events. Rectangle position and length correspond to event time and duration. The dashed rectangles represent alternative feasible schedule times for certain events which may have been rescheduled for specific reasons. These reasons or criteria can be viewed as specific system objectives which may vary with differing situations.

Specific Criteria

If the criteria of maintaining free time or minimizing the number of jobs on a system at any time is imposed, events may be rescheduled as at (A). This might represent distribution of work among TDRSS SA links. Such a criterion would tend to maximize the system's capability to respond to unscheduled or emergency requirements.

In particularly busy periods when system flexibility has been reduced, it may be desirable to maximize the amount of work scheduled for the system, to clear away any backlog of operations. Maximizing throughput in this way might mean in the STDN case maximizing the amount of data processed in a given time period. Techniques for maximizing throughput are illustrated graphically at (B) and (D) by simple advancements in schedule time, and at (C) by a reordering of events.

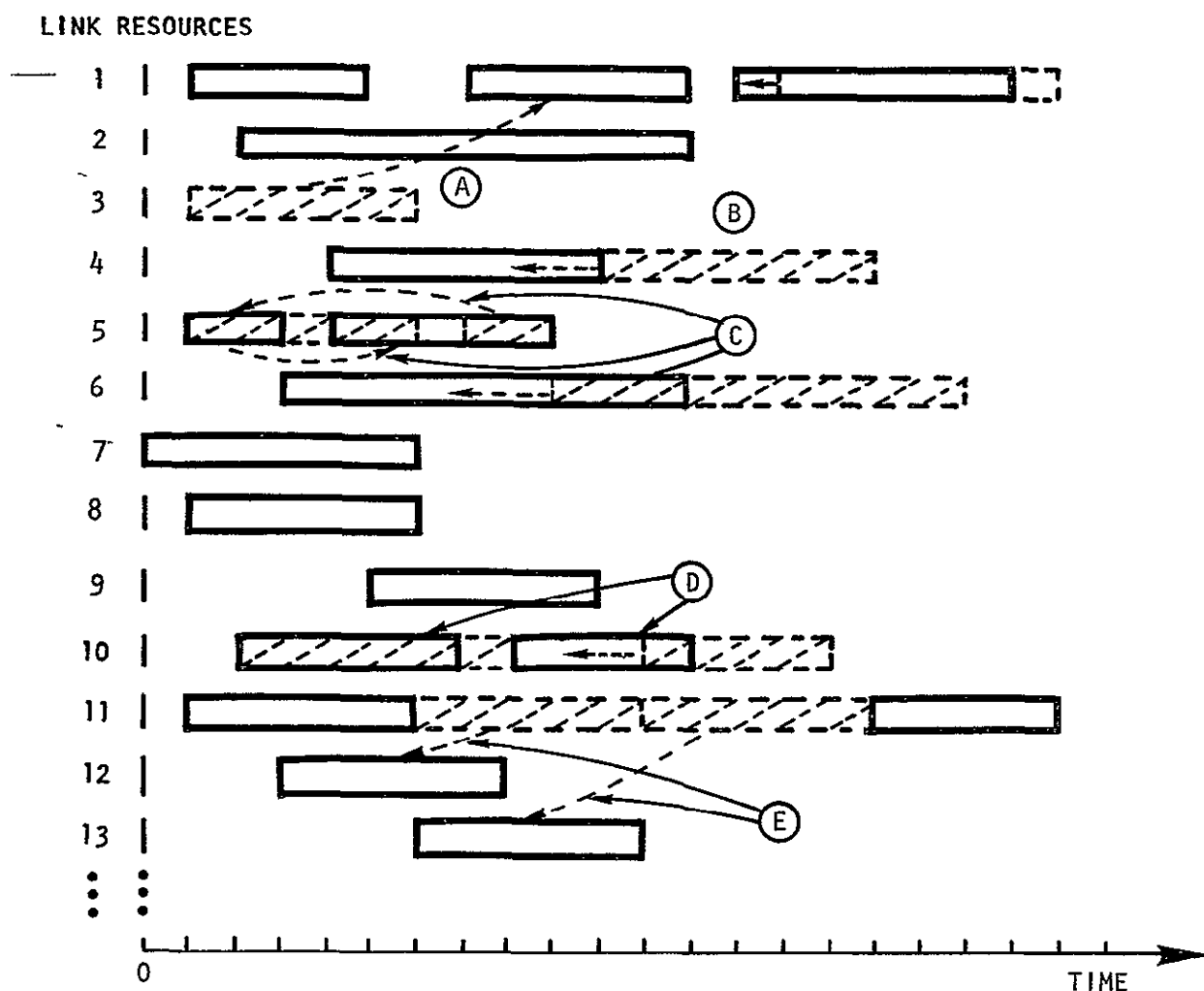
Finally, rescheduling to distribute workload is illustrated at (E). Lines 11 and 12 might be antenna systems at Madrid; line 13, an antenna at Rosman. Subject to orbital parameter constraints, distributing work in this way makes each link more flexible to accommodate unscheduled events since no one link is tied up for an extended period of time.

Optimal Scheduling

The systematic selection of one type of alternative schedule over others is what is meant by optimal scheduling. There are basically two categories of processing techniques which will facilitate the selection of an optimal schedule: total and implicit enumeration. Total enumeration involves identifying all feasible schedules and selecting one which best satisfies the system objectives.

Although such a technique is easily conceptualized, the number of calculations necessary to execute it becomes prohibitively large for a complicated problem. Implicit enumeration methods limit the number of possible schedules which are even considered. However, the logic in such processors is highly complex and execution times for such methods might also become very long if the problem was complicated.

SCHEMATIC EXAMPLE OF FEASIBLE SCHEDULES



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OBJECTIVE FUNCTIONS ARE USED TO ACHIEVE OPTIMIZATION

An objective function drives the scheduling process to maximize the degree of a desired effect in the schedule. In this manner the "best" or "optimal" schedule with respect to that effect is produced.

Objective Functions

The desire to produce optimal schedules is a major motivation in the field of scheduling theory. Schedules that will reduce costs, increase machine utilization, reduce idle time or increase throughput have obvious value to the manufacturing industry. The goal of competitive pricing and high profits are clear incentives to choose such objectives as the driving force for schedule preference.

In order to select its own objective function(s), STDN must consider its operational objectives. As identified in Phase I of this report, they include transparency of the network, uniformity of operation, flexibility to accommodate variations in load, and efficiency of operation. The scheduling algorithm itself can affect the flexibility and efficiency of the network most directly. The objective function chosen must not require an algorithm so unwieldy in size that timely response to emergencies is impossible, but at the same time it must be powerful enough to guarantee a high probability of being able to respond affirmatively to emergency requests. Thus the schedule produced should contain segments of useful free time to aid in contingencies.

An additional consideration may be the extent of the impact of short notice schedule changes on previously scheduled activities.

Establishing a data link to a particular POCC is of no use if that POCC, having been unable to receive data in a scheduled period because of higher priority unscheduled events, no longer has the manpower or ready hardware to accept the data.

As a result of such reflections, three candidate objective functions for STDN have been identified. It is not intended that this should be an exhaustive list, but rather these functions are recommended for STDN consideration and should indicate the flavor of other alternatives for the objective function.

Representative Examples

- 1) Minimize the number of simultaneous events at any given time.

To be able to guarantee necessary unscheduled service, STDN must be assured that if possible there are available channels on which the unscheduled user spacecraft might be contacted. Scheduling new

events in periods where less is being done within the network clearly contributes to this assurance. In addition routine maintenance could be more easily scheduled since it would be less likely that the entire network would need to be in operation at any one time.

- 2) Minimize time changes for previously scheduled events on update schedules.

As indicated, this is a user-oriented objective guaranteeing as far as is possible that individual POCC's will be able to establish their own routine schedules and be confident of receiving service.

Since user POCC staffing levels may well be event oriented, or user service requests dependent on POCC shift sizes, user satisfaction with STDN service requires that scheduled events not be subject to major time changes despite the fact that emergencies have to be met.

- 3) Maximize free time of STDN components during certain periods.

Similarly to the first candidate objective, this one is aimed at providing a schedule flexible enough to accommodate unexpected load fluctuations. It includes the added ability to adjust the scheduling process to normal daily patterns of intensive work and slow time, especially as regards unscheduled requests for service. It may become apparent that only during the 8 00 to 4 00 shift is there any significant unplanned activity. If so, the amount of free time for accommodating unscheduled requests should be increased on that shift by scheduling events away from that time period.

Whatever the choice of objective function, if a scheduling system is to be automated, and optimization is desired, the objective function must be fixed before the scheduling algorithm can be written. It is through the algorithm that the objective function drives the scheduling process.

Control Concept Refinement - ASR

ASR IMPLEMENTATION TECHNIQUES CAN BE BOUNDED

STDN schedules can be generated by a variety of systems differing in technical sophistication and capabilities. Selection is mainly dependent on desired objectives to be accomplished and available funding.

Techniques

For the purpose of discussion and comparison, schedule generating processes are divided here into manual, basic automated, and advanced automated types. It is not intended that these be viewed as discrete categories, but they are convenient labels for areas on a progressive scale of scheduling sophistication with the most naive approaches at one end and those based on the most advanced theory at the other. Movement along this scale implies movement along related scales of scheduling algorithm complexity, response time of the scheduling process, quality of the schedule produced, and of course cost. The choice of a scheduling algorithm and the system to execute the algorithm is based on these considerations.

Manual

In Phase I of this analysis, TDRSS loading was studied through the use of a random time scheduler and a zero order conflict resolver. It was demonstrated that such a system did not satisfy STDN needs if the projected load exceeded the baseline demands. Such excesses are inevitable when the Shuttle is to be supported. However, even the manual systems under discussion here can be more sophisticated than such a scheduling system since they allow searching for free time to be done in arbitrary increments both forward and backward from the requested time. In addition, conflict resolution even in the manual case allows adjustment of previously scheduled tasks in order to accommodate an additional one.

Manual scheduling techniques are characterized by their relative simplicity and low initial cost. The limit of the algorithm sophistication is the human brain's ability to do the comparisons and calculations necessary to complete the algorithm. Even so, the schedule lead times for such systems are generally fairly long and inflexible. The schedules produced by manual systems are adequate, but such a system can not cope with extremely large volumes of data to be handled or numbers of conflicts to be resolved.

Basic Automated

The basic automated systems result from attempts to computerize problems that might have been done by hand if time and data volume considerations did not make a manual system impractical. Thus, they run on basically the same algorithms as manual schedulers but with vastly improved response

times. The speed of such systems facilitates experimentation with queuing techniques or loading rules, rules that govern which job is placed where in the schedule. These techniques might involve comparisons too cumbersome for a manual scheduler, such as the length of all jobs available for a certain time slot, the number of jobs already scheduled in any given time period, etc. In addition, they make it practical for an individual user who is having activities scheduled to interact directly with the scheduling processor, instead of through a human intermediary, and receive a response to his request in short order. Furthermore, the volume of data such a system could handle is compatible with keeping concurrent schedules with variable lead times.

Advanced Automated

Advanced automated scheduling systems differ from basic ones fundamentally in the sophistication of the algorithms used. They employ theoretical results to tackle problems which would grow exponentially in size as the numbers of operations to be scheduled increased. Techniques used in these algorithms may include choosing successive maximum or minimum levels at each decision point in making the schedule (branch and bound), maintaining several alternative schedules based on several choices made at each decision point and choosing one at the end of the process (neighborhood sampling), and building the schedule to accommodate a particular identified bottleneck (critical path methods). Such techniques enable a computer to consider only those alternative schedules which offer analytically demonstrable advantages in terms of the objective functions chosen in the development of the particular algorithm. Clearly these algorithms are more complex than those required by the basic systems, and the running time for such a routine would be longer. But unless the loads became extremely large, the difference in response time capabilities of basic and advanced automated systems is small in comparison to the difference between manual and automated systems.

Implementation Costs

The initial costs of automated systems increase with the sophistication of the algorithm to be programmed. It is difficult to offer a firm estimate of the developmental costs for particularly advanced systems for which the algorithm cannot be specified without theoretical research. Often the difficulty of achieving results and the speed with which those results can be obtained is difficult to foresee. Despite this added initial cost, the estimated 2/3 decrease in manpower required by an automated system often could make even complicated systems cost effective (See page III-79 for details on staffing.)

The cost of the current scheduling system was compared with the cost of a fairly basic automated system for the period from 1979 through 1990. The information on the current system was derived from data provided by NASA. A staffing of 12 professional schedulers at an average of \$23K per year and 30 technicians doing clerical, keypunch, operating work at \$17K was assumed

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ASR IMPLEMENTATION TECHNIQUES CAN BE BOUNDED

The staffing for the automated system was based on an estimated 4 professionals needed to oversee the system. Then the current 3:1 ratio of technicians was used to derive a figure of 12 technicians supporting the automated system. Salaries for both skill levels were assumed to be the same as those currently found.

The costs of the systems were calculated with and without inflationary effects using the following equations.

$$\text{with inflation: } PV = CC + \frac{D_1}{i-g} \left[1 - \left(\frac{1+g}{1+i} \right)^N \right]$$

$$\begin{array}{l} \text{without inflation:} \\ \text{(constant} \\ \text{dollars)} \end{array} \quad PV = CC + D_1 \left[\frac{(1+i)^N - 1}{i \cdot (1+i)^N} \right]$$

where

CC = capital cost

N = lifetime, 12 years in this case

i = discount rate, 10%

g = inflation rate, 6%

D_1 = Disbursement at end of year 1

PV = present value or cost of the system

In the estimation, capital cost of \$400K for the automated system was used, while no capital cost was associated with the current system. This item was purely for software development. Using the other figures presented above rough cost estimates for the manual and automated systems were \$7.05M and \$2.66M respectively with inflation, and \$5.36M versus \$2.42M without inflation.

SCHEDULING TECHNIQUES AND TRADE-OFFS

MANUAL	BASIC AUTOMATED	ADVANCED AUTOMATED
<ul style="list-style-type: none"> • RELATIVELY SIMPLE ALGORITHM • COST EQUIPMENT & LABOR FOR MAX SYSTEM LOAD, LOW INITIAL INVESTMENT EST \$7 0 MILLION OVER NEXT 12 YRS • PRODUCES ADEQUATE SCHEDULE • REQUIRES FAIRLY LONG NON-FLEXIBLE LEAD TIME • LIMITED IN VOLUME OF DATA IT CAN HANDLE • SLOW RESPONSE CAPABILITY 	<ul style="list-style-type: none"> • RELATIVELY SIMPLE ALGORITHM • COST INCREASED INITIAL INVESTMENT IN SOFTWARE DEVELOPMENT, DECREASE IN MANPOWER BY 2/3, EST \$2 7 MILLION OVER NEXT 12 YRS • PRODUCES ADEQUATE SCHEDULE, FACILITATES EXPERIMENTATION WITH LOADING RULES • FLEXIBLE LEAD TIME • HANDLES LARGE VOLUME OF DATA • RAPID RESPONSE CAPABILITY 	<ul style="list-style-type: none"> • RELATIVELY COMPLICATED ALGORITHM • COST INCREASED INITIAL INVESTMENT IN SOPHISTICATED SOFTWARE DEVELOPMENT, DECREASE IN MANPOWER • PRODUCES OPTIMAL SCHEDULE FOR CHOSEN OBJECTIVE FUNCTION GIVEN THE LOAD • FLEXIBLE LEAD TIME • EFFECTIVENESS MORE SENSITIVE TO LOAD INCREASES • RESPONSE MAY BE LESS RAPID THAN BASIC AUTOMATED

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Control Concept Refinement - ASR

JOB SHOP THEORY CAN BE APPLIED TO THE STDN SCHEDULING PROBLEM

It is important to focus scheduling algorithm investigations to the applicable segment of scheduling theory.

Job Shops

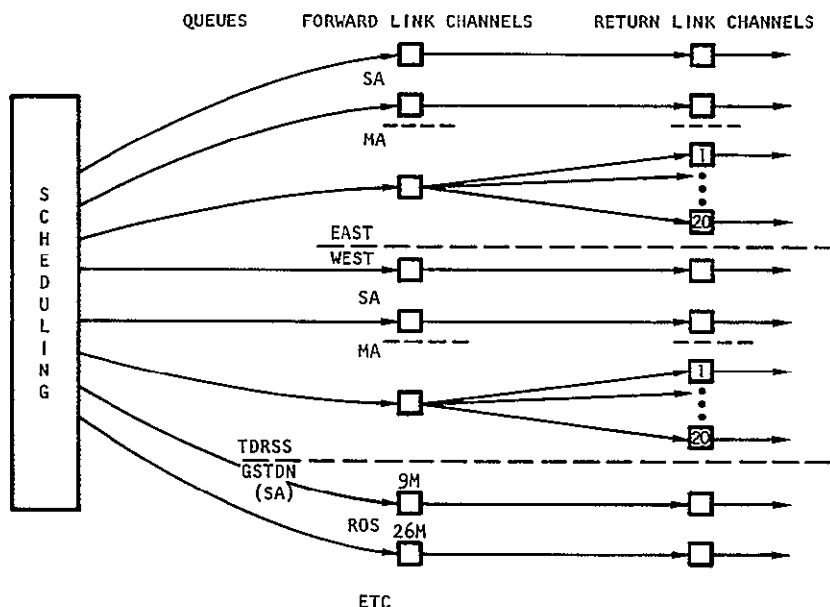
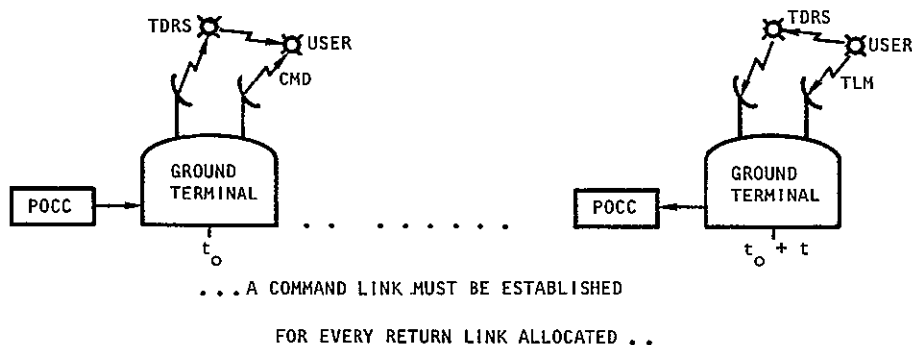
The so-called "job shop" is a tool to aid in the configuration and analysis of scheduling problems. Its essential elements are the jobs, the machines, and the time parameters for each job. The jobs to be done may involve more than one operation. They are simply convenient aggregates of the work to be accomplished, receiving data from a satellite, for instance. The machines are basically resource type items which can be applied to, or which operate on the jobs to complete the work. Included under the heading of time parameters are the processing time, arrival time and due time for each job. Having established how many machines make up the shop, actual job shop types fall into a two-dimensional array characterized by the sort of job queue, and the type of flow pattern they exhibit. Jobs may either be ready for processing when the shop begins work, or they may arrive for processing during the course of shop operations. These job queue varieties are referred to as static and dynamic, respectively. Normally the operations necessary to complete a job are fixed and thus the machines which work on it are predetermined. However, the order in which the operations are carried out may vary from fixed to arbitrary. The former extreme typifies a flow shop, while the latter typifies a random route shop.

Level of Detail

Application of this sort of a theoretical framework can be made to the STDN scheduling problem at various levels of detail. If STDN were to select some type of optimization, the network should be viewed as a system of forward and return links. Then STDN appears to be a modified flow shop with two classes of machines and a mix of static and dynamic job queues. A further breakdown into GSTDN and TDRSS elements can be made yielding two parallel job shop problems, tied together by an equipment which may be common to their operations, such as NASCOM lines. In both GSTDN and TDRSS, the forward and return links are the two classes of "machines." Before any data can be taken from a satellite, the spacecraft must receive a signal to transmit. Thus a forward or command link must be allocated to the user before an event involving a return link can occur. This is the fixed order typical of flow shops. The taking of data need not follow the command, making transmission possible instantly, nor must there be a return link phase of the event. The "forward before return" rule holds in any case. Note that machine "classes" are identified since a number of channels may be available, any one of which could handle the user's request equally well.

The job queues in this job shop have static and dynamic aspects. Scheduled generic requests make up a fixed job load which is augmented by incoming requests which are not predictable in terms of either number or frequency except perhaps on the average.

ORDER OF STDN SERVICE FUNCTIONS



Control Concept Refinement - ASR

EXISTING SCHEDULING ALGORITHMS POTENTIALLY APPLICABLE

Considerable theoretical work has been done in the field of scheduling which may contribute to the solution of STDN's scheduling problem; however, direct application of existing work to the total problem is unlikely.

N/2 Job Shop

Scheduling problems are among the most difficult problems in mathematics simply because of the enormous, though finite, numbers which begin to appear as the number of operations to be scheduled grows. For general problems such as optimizing a schedule for an n job/ m machine job shop, "although it is easy to state and to visualize what is required, it is extremely difficult to make any progress whatsoever toward a solution." (Reference 19) Being difficult, however, scheduling problems have drawn considerable attention, and STDN may be able to apply proven techniques and results to various parts of its overall scheduling problem

In light of the configuration of STDN shown on the previous page, work on the N/2 job shop could be expected to prove the most enlightening in a search for an overall optimizing algorithm for the STDN schedule. The two machines correspond to the two machine classes, forward and return links, but the job queues in existing studies are normally all static.

Branch-and-bound algorithms may be useful because they can offer some confidence in the quality of a schedule without attempting explicitly to find the absolute best schedule.

These two types of scheduling problems are highlighted with asterisks in the accompanying figure because they appear the most promising for application to the entire STDN scheduling problem.

Other Methods

Other types of scheduling methods might be used to ensure efficient use of equipment systems. Antennas could be viewed as the single machine in a "finite sequencing for a single operation" type problem. Indeed, if any one equipment system were identified as presenting a major constraint to network support capacity, optimization of the schedule for that system might have to be the driving force in producing a network-wide schedule

Additional problem types are noted here and work on them may help alleviate parts of the STDN problem, but it is important to point out that the measures of effectiveness normally associated with existing work in these areas are

not identical with the types of objectives mentioned above for STDN. It is not clear, for example, that getting scheduled work completed as quickly as possible is of any benefit to STDN. Nor is increased throughput capability when no additional support is required of any obvious value, especially when it might decrease the systems ability to accommodate short notice requests. Indeed the actual objective functions of STDN may change depending upon the workload at a given time. The time variation of objectives as well as the uniqueness of those objectives constitute a major difference between the STDN scheduling problem and problems which have been addressed in research on scheduling.

SURVEY OF SCHEDULING ALGORITHMS

ALGORITHM/PROBLEM TYPE	HOW IT MAY APPLY	USUAL M O E
*N/2 JOB SHOP	CORRESPONDS TO FORWARD AND RETURN LINK ARRANGEMENT, INPUT USUALLY STATIC	TOTAL SCHEDULE TIME
*BRANCH AND BOUND ALGORITHMS	CHOOSE CHANNEL/STATION TO AVOID HEAVILY LOADED NETWORK ELEMENTS	DISTANCE, COST, TIME
SELECTION IN SINGLE-SERVER QUEUING SYSTEM	REQUESTS PASS THROUGH NETWORK IN NEAR STRAIGHT-LINE, CHOICE OF INDEPENDENT ROUTES	MEAN FLOW TIME, NUMBER OF JOBS IN SHOP
CRITICAL ROUTE ANALYSIS	MICRO LEVEL IMPROVE TURN-AROUND TIME ON STATION	SHORTEST ROUTE PER JOB
FINITE SEQUENCING FOR A SINGLE OPERATION	MICRO LEVEL SCHEDULING INDIVIDUAL PIECE OF EQUIPMENT, E G , ANTENNA	FLOW TIME, WAIT TIME, SCHEDULE TIME
COMPUTER SEQUENCING AND LOADING/SERIAL PROCESSOR	MICRO LEVEL USE OF PRECEDENCE SPT PRINCIPLES	MEAN THROUGHPUT
SCHEDULING MULTIPROGRAM COMPUTER	PRECEDENCE, SPT NOTIONS	MEAN FLOW TIME, MEAN THROUGHPUT

* PROBLEM TYPES OF PARTICULAR INTEREST TO STDN

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ALGORITHM RECOMMENDATION

STDN scheduling in the TDRSS era should be accomplished initially with a multiple-pass enumeration algorithm in an automated environment.

Overview of Recommendation

In light of the STDN mission model, the role to be played by the automatic scheduling routine as identified in Phase I of this study, and the range of scheduling options described in this report, the following recommendations can be made for the adaptation of the STDN scheduling process to the TDRSS era. Regardless of the algorithm selected for the scheduling process, the need for automation of the execution of that algorithm to the maximum degree possible should be recognized. A relatively simple, but adaptable software package should be chosen which begins with a multiple pass feasibility search and allows the addition of heuristic loading rules as subroutines. Such rules include uniform distribution of jobs, shortest processing time first, scheduling requests from a particular project first, first in-first out, and so on. Network schedulers should be able to use loading rules in different combinations, depending on the needs of the scheduling system, to deal with any problems and maintain system flexibility. In terms of the scale of sophistication described earlier, such a system falls in the range between basic and advanced automated systems.

The ability to use specific applications of existing optimization algorithms or particular equipment systems should not be precluded. The STDN scheduling problem must still be configured in complete detail. In the course of that process, particular segments of the problem may be identified to which existing techniques can be effectively applied.

Top Down Approach

It is not necessary that all subroutines and suboptimizing techniques be available when the ASR is made operational, but they should be available as the STDN workload reaches more stable levels in the mid 1980's. A top-down approach to software development can be used. The search algorithm, which should be capable of identifying a number of feasible schedule times for an event, is central to the proposed system and should be developed first. The top-down approach guarantees that all subroutines developed later are compatible with existing segments of code by specifying interface conditions which new segments must meet before those new pieces are written. Thus, even if the exact specifications of some subroutine are not known when the software coding is begun, the subroutine can be easily added at a later date.

Software products developed in this way are highly modular. This increases the system's flexibility since different operating modes could be easily

imposed in response to changes in workload by simply calling up different modules. In addition training and learning on the system is aided by the top-down approach since the segments of code which are finished always form an operational whole.

RECOMMENDATIONS FOR STDN SCHEDULING IN TDRSS ERA

BASIC AUTOMATED SYSTEM WITH ABILITY TO USE PROGRAMMABLE, HEURISTIC LOADING RULES

- HARDWARE AUTOMATED TO MAXIMUM DEGREE POSSIBLE
- SOFTWARE MULTIPLE PASS FEASIBILITY SEARCH WITH ..
 - FLEXIBILITY FOR HEURISTIC LOADING TECHNIQUES
 - UNIFORM DISTRIBUTION OF JOBS
 - FIRST IN - FIRST OUT
 - SHORTEST PROCESS TIME
 - OTHERS
 - CAPABILITY TO ALLOW SPECIFIC APPLICATIONS OF EXISTING OPTIMIZATION ALGORITHMS E.G. SEQUENCING FOR SINGLE SERVER FOR SA TDRS ANTENNAS

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Control Concept Refinement - ASR

THE ASR SHOULD UTILIZE DEDICATED HARDWARE

Although the ASR software could potentially be executed in a batch mode on existing GSFC general purpose computers, the requirements for such operations suggest dedicated hardware.

Processing Requirements

The ASR hardware/software package may be required to respond to significant data base queries, perform numerous file/data base updates, execute scheduling algorithm frequently and accommodate a spectrum of user I/O equipment. However, no current requirement can be identified which requires a real time operating task to be resident in the ASR system. The term "real time operating task" should not be confused with a fast response capability. Although seeming a semantics problem, the difference in the two concepts can impact the hardware system supporting the ASR. A fast response capability can be provided by an operating structure which allows the CP to respond to an interrupt as soon as on-going processing is completed. Thus if one is entering a request to the ASR, via a CRT terminal for example, there may be a small perceptable delay before the ASR accepts the input which is being held within the terminal at the user location.

Alternatively a real time operating task implies an operating system which stops on-going CP processing when particular interrupts occur. For example if a message appears at the I/O, and this message appears at a high rate, the message must be removed from the line and buffered before the next arrives or it will be lost.

Because the users of the ASR are not expected to generate requests of the ASR algorithm at a rate which will require ASR responses in the micro-second time frames, two hardware options were investigated for support of ASR software.

Dedicated Hardware Considerations

It was assumed that the schedule would accommodate one month in the future. All events would be resolved to the nearest minute. Using 30 days in a month the storage requirement for the schedule would be approximately two million characters. For the 30 days, 43,200 time slots are required. 50 to 60 characters per time slot were assumed for the scheduling information.

To prevent multiple read/writes of the same file, five "tinker" files were assumed. These are copies of the current schedule with which up to five users may "play" while not impacting the integrity of the data base until firm decisions have been made. With two million characters per file, five tinker files plus the original requires 15-20 million bytes (16 bit bytes) of storage.

The CPU for the ASR should be identical to that used in CASMS. This approach yields several benefits. Software may be developed on one machine with confidence that it will work on the other. During situations where operation is degraded, the CASMS CPU may be used to assume the tasks of the ASR or vice versa if desired. Identical CASMS and ASR CPUs will provide an extremely flexible hardware configuration

Remaining components of the ASR system are identified in Appendix H .

Batch Processing Considerations

As indicated above, technical considerations suggest investigation of a batch processing mode ASR executed on existing GSFC hardware. The major considerations in this approach are:

- The capability of existing systems to support multi-user operations as the same program in a batch mode or provide the requisite "tinker" files
- The probability that the NOCC will be provided "benevolent dictatorship" guarantees on existing GSFC general purpose machines.

This latter consideration has lead to the recommendation that dedicated computer hardware be obtained for the ASR. Emergency situations will occur wherein the NOCC must have extremely high confidence in the ability to access the ASR. On a general purpose machine this amounts to providing the NOCC with the highest operational priority with the understanding that it would not be used unless absolutely required. It has been our experience that the only way such guarantees can be enforced is with control over the actual machine. Otherwise one of the parties to the agreement soon violates it in the other's opinion. Therefore in the long run, considering both technical aspects and operational realities, a dedicated minicomputer of some sophistication is recommended for ASR application.

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Control Concept Refinement-ASR

AUTOMATION REQUIRED

Automation of the STDN scheduling process is made necessary by the volume of work to be done and the quality of service to be provided in the TDRSS era.

Workload

There can be little doubt that the STDN scheduling process should be automated. Projections based on the network mission model show STDN scheduling a minimum of 1500 hours of support each week in the 1980's (see Appendix F, GSTDN DEMAND, TDRSS DEMAND). Perhaps a manual scheduling system could handle such a level of demand but not in the way that meets GSTDN objectives. The goals of transparency and flexibility require automation of scheduling for the reason identified in the discussion of automated scheduling systems above.

Benefits

The rapid response capability of an automated system is required for dealing with emergencies and unscheduled requests. The user must receive a timely response to his request for services if some problem arises in controlling his spacecraft or if some rare environmental conditions exist about which he would like to gather data. Even if the network loading were light and humans could provide instant confirmation of STDN's ability to fulfill such a support request, a more uniform, reliable, and efficient contact can be made if the connection between user and scheduling process is directly between man and machine. The work involved is routine, conceptually simple, and repetitious, characteristics which suggest assigning the tasks involved to machines rather than men. This of course implies an automated scheduling routine of some variety. User autonomy in scheduling events and the ability to test hypothetical alternative schedules can also be greatly enhanced by an automated system.

In addition to speed, an automated system offers large memory capabilities. In order to maintain several schedules with different lead times, vast amounts of data on satellite orbits, TDRS viewing angles, scheduled service, and so on must be kept on file. With the memory capacity offered by a machine, different users could plan events with lead times better suited to their needs.

Finally, in the comparison of schedule generating types, it was shown that automation can lead to significant savings in operating costs.

Other Considerations

A potential side effect of the high number of scheduled support hours will be the increase in the number of conflicts requiring resolution. Such

situations would arise for instance when two shuttle spacecraft were operational (Reference 1). Again the speed of an automated schedule will be essential since it can more quickly offer alternative resolutions to conflicts, and it can facilitate testing of different loading techniques for their impact on a congested schedule. Since no real problems are anticipated before the mid 1980's, software development could be viewed as an 8 year rather than a 2 year problem. As the automated scheduling routine is being developed, sensitivity analysis should be performed to determine its ability to deal with hypothetical increases in loading significantly in excess of current projections.

NEED FOR AUTOMATION

- THOUSANDS OF EVENTS SCHEDULED EACH WEEK; 1500-2000 SCHEDULED HOURS
- RAPID RESPONSE - "WHAT IF" CAPABILITY TO DEAL WITH
 - UNEXPECTED REQUESTS FOR SERVICE
 - EMERGENCIES
- ABILITY TO ALLOW INCREASED USER FREEDOM AND INTERACTION IN SCHEDULING EVENTS
- ABILITY TO MAINTAIN MULTIPLE SCHEDULES CONCURRENTLY (E.G., SCHEDULES WITH 1, 2, 3 OR 4 WEEK LEAD TIME)
- ABILITY TO RESOLVE INCREASING NUMBER OF CONFLICTS FOR TDRSS SA LINKS AND GSTDN LINKS AS SATELLITE LOAD INCREASES

Control Concept Refinement-ASR

IMPLEMENTATION OF A HIGHLY SOPHISTICATED OPTIMIZATION ALGORITHM IS NOT RECOMMENDED

The uniqueness of the STDN operational objectives, combined with the relative complexity of the system, effectively thwarts the implementation of optimal scheduling algorithms.

Off-the-Shelf Algorithms

As indicated above, a variety of scheduling problems have been investigated to determine optimal solutions. However, not all of the investigations have been successful. Algorithms have been formulated for smaller, specific schedule problems but not for generalized problems (e.g., the general job shop problem). Furthermore, these problems are traditionally configured on quantifiable criteria such as mean flow times, system throughput, and total schedule time.

On the other hand, the STDN schedule configuration is complex and not specific. The system will be composed of more than 20 forward link processors and nearly 40 return links with varying performance capabilities. The problem is further complicated by NASCOM link availability and capabilities.

In addition, the operational objectives are difficult to quantify. Generically stated, the objective of the scheduling efforts is to provide the maximum service possible to STDN users. This objective consists of a number of more specific yet qualitative objectives such as system flexibility, quality of service, and the equitable distribution of services. Even when attempts are made to quantify these goals, the traditional measures are not obtained. The phenomena described above clearly indicate that the application of an "off-the-shelf" optimization algorithm is highly unlikely.

Development Costs

Generalized scheduling problems have been repetitively challenged by many analysts eminent in the field of Operations Research, yet none have been able to formulate optimal algorithms. Although this does not preclude the existence of such algorithms, it does indicate that any attempts to develop an optimal STDN schedule algorithm would be very costly and may well end in failure. Even if it were assumed that the algorithm could be developed, it would be difficult to justify the high costs because the magnitude of the beneficial impacts provided by such a processor would be difficult to ascertain. A more basic algorithm capable of multiple-pass schedule identification could be developed at much lower costs, and heuristic loading techniques could provide significant system benefitation. In addition, projected system loads indicate that absolute optimization may not be necessary. For example, the projected TDRSS-SA loading is shown in Appendix F.

The figure shows that even when TDRSS resources are reduced by 50 percent due to Shuttle utilization, a maximum of 75 percent of the remaining resources are occupied during the four-quarter period of peak load which is expected to occur in 1982.

Specific Applications Are Not Prohibited

The above discussion does not exclude the application of specific "off-the-shelf" algorithms. In fact, the overall system can profit from their utilization when a subsection of the STDN is configured in a specific, finite-component problem and solved as a subroutine to the principal algorithm.

Such an application might involve the use of the single-server or finite element job-shop algorithms for the scheduling of TDRSS-SA and GSTDN antennas during peak load periods. The antenna motion would be represented by set-up times, and the subroutine objective would be to maximize mean flow times or system throughput. Such subcomponent optimization would greatly enhance the overall system performance.

OPTIMIZATION PRESENTS DIFFICULTIES

- UNIQUENESS OF STDN OBJECTIVE FUNCTIONS
 - TRADITIONAL JOB SHOP ANALYSIS AIMED AT MINIMIZING FLOW TIME, MAXIMIZING THROUGHPUT, ETC
 - "OFF-THE-SHELF" IMPLEMENTATION UNLIKELY
 - STDN OBJECTIVE MORE QUALITATIVE. PROVIDE FLEXIBILITY OF SERVICE, RESPONSIVENESS, ETC.
 - DEMAND IS MANAGEABLE WITHIN CONSTRAINTS OF AVAILABLE NETWORK SUPPORT TIME WITHOUT THEORETICAL ANALYSIS
- COST EFFECTIVENESS OF EXTENSIVE SOFTWARE DEVELOPMENT QUESTIONABLE
- LOADING RULES CAN CONTRIBUTE SIGNIFICANTLY TO ACHIEVING MANY SCHEDULING OBJECTIVES
- PROVEN TECHNIQUES AVAILABLE TO MAXIMIZE EFFICIENCY OF PARTICULAR STDN EQUIPMENT SYSTEMS
 - ANTENNA MOVEMENT
 - SCHEDULING EQUIPMENT MAINTENANCE
 - CHOICE OF COMMUNICATIONS LINE

Control Concept Refinement - ASR

PROJECTED REQUIREMENTS CALL FOR A QUASI-SOPHISTICATED AUTOMATED PROCESSOR

Projected system loads and resources indicate that the TDRSS era STDN will be faced with scheduling problems which require moderately sophisticated algorithms and automated schedule processing.

Summary

The figure provides a summary of the key results of the Phase II research in scheduling. The future STDN operation will indeed be faced with a scheduling problem based on projected user loads. However, the anticipated scheduling problem can be controlled with an automated multiple pass (quasi-sophisticated) schedule processor. User cooperation via system interaction and request modes is essential for equitable and efficient system operation. Combined with heuristic loading rules built into the algorithm, they will provide sufficient flexibility to ensure the quality of service sought by STDN in the TDRSS era.

The concept of optimization with respect to a specific objective was initially very attractive. However, an advanced algorithm was not recommended. This recommendation was based on two key points: 1) the existing state of the art in optimal schedule algorithms is limited in that solutions to generalized problems have not been obtained, and 2) the high developmental cost of the software package, assuming one could be developed, would be difficult to justify because acceptable service could be obtained with more basic, lower costing systems. In addition, the incremental benefit provided by strict optimal scheduling would be difficult to ascertain.

Suboptimization, or optimization on a more specific level, is recommended. Off-the-shelf optimization packages could be applied on a component basis. Subcomponent optimization will enhance the overall operation of the system.

Future Research

There are five major steps for the implementation of a scheduling System. These steps are

- (1) Problem recognition by management,
- (2) Education of NOCC/Scheduling and user personnel,
- (3) Establishment of standards,
- (4) Development of schedule processor, and
- (5) System performance monitoring.

The first two steps have been addressed by NASA and were presented in the Phase I report. The preliminary recommendations for the establishment of standards have been discussed herein. Continued research is required to develop specific values for three areas addressed in this analysis: problem configuration, objective function selection, and minimum service standards.

The STDN resources must be configured and all constraints described in detail to facilitate system analysis. Such configuration is required to delineate the nature of the system, system elements and their interrelationship, and to identify all components of the system which may lend themselves to scheduling by off-the-shelf optimal algorithms.

The specific objectives of the system must be defined to scope the "rules of the game" for the scheduling algorithm. These criteria must be specified in detail to facilitate the incorporation of techniques designed to increase the capability of the basic, multiple-pass processor to the attainable level of a quasi-advanced schedule algorithm. For example, the generic criterion of maximizing system capability to process unscheduled or emergency requests can be stated in terms of maximizing the free time for each link category at any given time, or continuously minimizing the number of jobs on each system component. The capability of periodically interjecting a priority scheme may be necessary, but the above objective would minimize the probability of having to use it.

Finally, the minimum level of required service must be specified. This parameter may be viewed as a design factor. The mission model shown graphically in Appendix F has indicated that in peak period operations, thousands of jobs will be scheduled each week resulting in 1500 to 2000 scheduled hours. This load, compounded by an extended lead time capability, requires a large data processing/storage capability. This system capacity must be identified, possibly in event-rate for extended periods of time, and a design "safety" factor selected. Because the estimates of loads are projected, an element of uncertainty is present. For this reason, it is advisable to "overdesign" the processing system to ensure system reliability in continued service. When this information is available, development of the actual schedule processor can begin.

SUMMARY

- THE ESSENTIAL COMPONENTS OF A SCHEDULING PROBLEM ARE IDENTIFIABLE IN STDN OPERATIONS
- SCHEDULING MAY BE PERFORMED WITH VARIOUS DEGREES OF SOPHISTICATION
- OPTIMIZATION IS ALWAYS DONE WITH RESPECT TO A PARTICULAR CHOSEN OBJECTIVE FUNCTION
- FUTURE LOADS REQUIRE ADDED SCHEDULING CAPABILITIES OF AN AUTOMATED ALGORITHM
- HEURISTIC LOADING RULES SHOULD PROVIDE SUFFICIENT FLEXIBILITY TO ENSURE THE QUALITY OF SERVICE SOUGHT BY STDN IN THE TDRSS ERA
- UNIQUENESS OF STDN PROBLEM AND LIMITED INCREMENTAL RETURN OVER HEURISTIC ALGORITHMS DISCOURAGE EXTENSIVE THEORETICAL RESEARCH FOR SOFTWARE DEVELOPMENT

ITEMS FOR CONTINUED INVESTIGATION

- PROBLEM MUST BE DEFINED AND CONFIGURED IN DETAIL INCLUDING RESOURCES, INTERFACES, PREDICTS, AND MISCELLANEOUS CONSTRAINTS
- AN OBJECTIVE FUNCTION MUST BE SELECTED
- MINIMUM SERVICE STANDARDS OR REQUIREMENTS MUST BE DEVELOPED

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CONTROL CONCEPT REFINEMENT
—
CASMS

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Control Concept Refinement - CASMS

CONTROL AND STATUS MONITORING SYSTEM (CASMS) AUTOMATES STDN INTERFACES

Phase 1 Analysis identified CASMS as a hardware/software package that provides summaries of network status parameters and real time estimates of data quality.

Introduction

The Phase I analysis identified a set of STDN operations control concepts. One of the basic cornerstones to all concepts was the Control and Status Monitoring System (CASMS). The following paragraphs summarize the Phase I analysis results applicable to CASMS. The remainder of this section then refines the CASMS concept to the point where hardware and software requirement estimates can be made.

Status Monitoring

Information pertaining to status, STDN element configuration, and the occurrence of events must be exchanged between the NOCC, network elements, and users during the normal course of network operations. The CASMS is used to automate the transfer of this information. CASMS can receive status and event indications via "level type" signals activated by switch positioning at the transmitting element. For example, a green status indication could be transmitted to CASMS from a GSTDN site by turning the "STATUS" switch on a console to the appropriate position. Signals received by CASMS are catalogued, stored and presented for visual review by operations management personnel. Configuration information may be transmitted to CASMS via formatted messages which are also catalogued, stored and presented for visual review. The software within CASMS then provides periodic status and/or event mark occurrence information, either periodically or on an "as changed" basis. Additionally, an interrogate/response capability is provided within CASMS which allows acquisition of specific information on an "as needed" basis.

Data Quality

CASMS also has the capability of providing real time estimates of data quality. These measures are necessary for the NOCC to obtain measures of STDN performance as it fulfills its data transfer function. Two fundamentally different techniques of obtaining real time data quality measures were considered in the analysis of Phase I: performance parameter monitoring and data inspection. CASMS can support either method of data quality measurement. However, the hardware and software requirements are significantly different for the two approaches. Additionally, the interfaces between CASMS and the NASCOM data communications network change as a function of the chosen data quality estimating approach. In general, CASMS

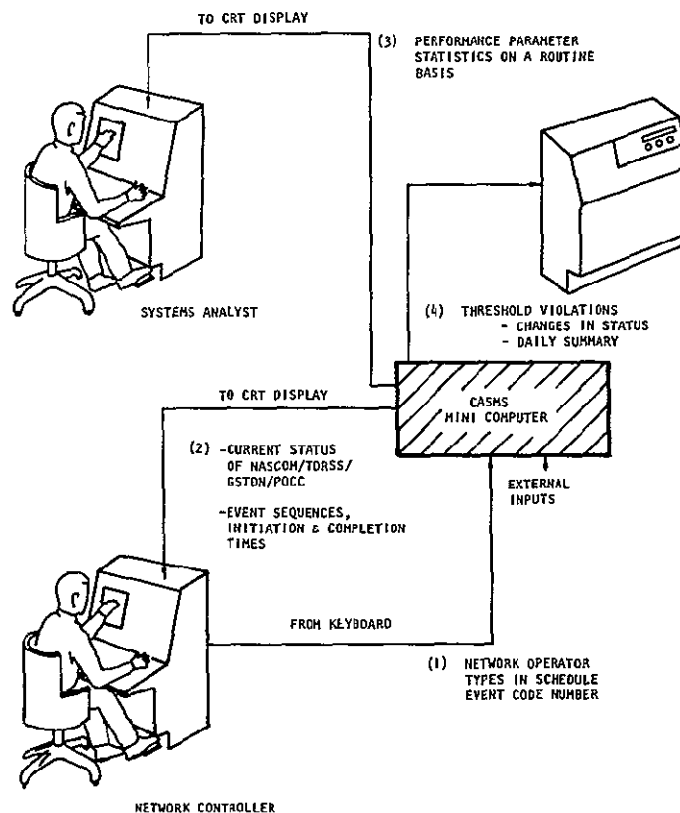
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tends to be significantly more complex in both hardware and software when supporting the data inspection technique. The performance parameters monitoring scheme tends to minimize equipment and software development requirements.

The implementation of a performance parameter monitoring scheme lends itself to a more complete response to poor data quality, including fault isolation and corrective action support. However, it must be impressed upon users that rapid service degradation identification is necessary.

Further, all parties involved must speak a common language when identifying poor data quality. For example Bit Error Rates (BER's), missing frames, missing blocks must be specified rather than "garbled data." Thus, CASMS must have the necessary information on BER's, frame and block counts, to respond to user inquiries and ascertain accountabilities for data degradation.

CASMS OVERVIEW



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Control Concept Refinement - CASMS

CASMS OPERATION SUPPORTED BY A SMALL MESSAGE SET

Five categories of messages with less than 100 bits each will provide the requisite CASMS information.

MESSAGE DESCRIPTIONS

Five CASMS message categories have been identified, the purpose of each is discussed in an individual paragraph below. It should be noted that the messages described below are those considered critical for real-time control system operations. Two alternatives exist for the transfer of these messages between the NOCC, STDN elements, and network users. These messages could be transmitted via the 9.6 KBS digital channels assumed to exist between the NOCC and TDRSS/GSTDN ground stations. Secondly they could be interleaved upon the 1.5 MB and 56 KB data lines. The fundamental consideration is the sampling rate associated with each link Appendix D treats these considerations in some detail. Current analyses indicate the 9.6 KB "administrative circuit" should support the CASMS information transfer requirement.

Network Element Status (NES) is the message that is transmitted to CASMS during a predefined interval before a scheduled contact. It is to indicate to NOCC Operations Management that scheduled elements are either go or no-go for the scheduled event. An interval is recommended to ensure that elements cannot indicate "go" for all scheduled contacts at one time. This message essentially is the automated equivalent to the pre-pass verbal check currently executed by network controllers about 15 minutes prior to the pass.

The Element Status Change (ESC) message notifies NOCC Operations Management that an element in the network or user equipment has either changed from green-to-red or from red-to-green. The terms "Green" and "Red" are used herein to signify that an element is ready and operational or not ready/ not operational respectively.

The NASCOM Error Status Word (ESW) is the flag which is currently set after NASCOM performs its PED code comparisons. It is used currently to indicate whether a block of data potentially contains an error.

Event Marks (EMK) signify to Operations Management and/or network elements that specific events associated with a contract have occurred. For example, TDRSS acquisition sequence initiated or terminated may be viewed as event marks.

The final category of messages, Performance Parameters (PMT), are those utilized by CASMS to perform real-time assessments of data transmission quality. They are transmitted from the STDN ground stations to the CASMS as a periodic basis whenever a contact is in progress.

CASMS MESSAGE SIZING

MSG ID	SOURCE ID	TIME	STATUS CODE	SCHEDULE EVENT ID
-----------	--------------	------	----------------	----------------------

MESSAGE CATEGORY 1 NETWORK ELEMENT STATUS 79 BITS

MSG ID	PORT/ LINK ID	TYPE OF CHANGE	TIME (OF CHANGE)	CAUSE OF CHANGE	ESTIMATED TIME TO REPAIR
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MESSAGE CATEGORY 2: ELEMENT STATUS CHANGE 83 BITS

MSG ID	USER ID	PORT ID	ERROR STATUS	TIME
-----------	------------	------------	-----------------	------

MESSAGE CATEGORY 3: NASCOM ERROR STATUS WORD 55 BITS

MSG ID	SCHEDULE EVENT ID	TIME	SOURCE ID
-----------	-------------------------	------	--------------

MESSAGE CATEGORY 4 EVENT MARKS 75 BITS

MSG ID	PORT/ LINK ID	TIME	PARAMETER ID	PARAMETER VALUE
-----------	---------------------	------	-----------------	--------------------

MESSAGE CATEGORY 5. PERFORMANCE PARAMETERS 60 BITS

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Control Concept Refinement - CASMS

CASMS OPERATION SUPPORT BY A SMALL MESSAGE SET

Message Sizing

MESSAGE IDENTIFICATION (MSG ID) signifies to CASMS the category of message being received. This parameter is used in fundamental rating operations within the CASMS software. Since there are five message categories, a minimum of three bits are required for this parameter.

Whenever TIME is used in a message, a requirement for the day, hour, minute and second has been assumed. Representation of 365 days requires 9 bits while the number 60 (hours, minutes, or seconds) requires 6 bits. Therefore, representation of the time requires 27 bits.

Sources for messages, SOURCE ID, could be any of the STDN users. Because of the variable nature of this number, enough capacity to support over 1000 users has been allocated with 10 bits.

SCHEDULE EVENT ID uniquely identifies each STDN supported contact and activities. Within the event number it has been assumed that it is desirable to code the location of the STDN element supporting the contact/event to some degree of detail. This could include identifying the SA link associated with the TDRSS East satellite for example. Therefore in addition to TIME, 8 bits have been reserved for STDN element identification (256 unique "links"). Thus the total bits to accommodate the SCHEDULE EVENT ID is 35.

The communications PORT ID has been allocated 11 bits so that over 2000 unique ports can be identified. STATUS CODES were assumed to consist of 1) "go" (green), 2) "no-go" (red), 3) degraded/limited support (amber), and 4) other. Four bits accommodate a flag setting of these conditions as well as growth to 16 unique status state identifiers. TYPE OF CHANGE with 5 bits accommodates all combinational possibilities of the above changes of state. CAUSE OF STATE CHANGE has been allocated 10 bits allowing for coding/definition of over 1000 different state change mechanisms.

Based upon information in the TDRSS Performance Specification as well as investigation of potential performance indicators, 7 bits have been allocated to performance PARAMETER ID. In the "flag set" mode, up to 7 parameters can be identified. In the "combinational mode" up to 128 parameters may be identified. This range would seem to bound the requirements for this aspect of services quality determination. Similarly a value of 12 bits was chosen to represent the PERFORMANCE PARAMETER VALUE. This was deemed sufficient for both fixed and floating point notation.

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As can be seen from the above, all messages should be compatible with a 100 bit message format. Additionally, as the definition of the system is enhanced, capability for increasing any of the parameter bit sizes has been accommodated.

<u>CASMS MESSAGE PARAMETER SIZING</u>		
<u>PARAMETER</u>	<u>ELEMENT</u>	<u>BIT SIZE</u>
1. MESSAGE ID	N/A	3
2. SOURCE OR USER ID	N/A	10
3. PORT/LINK ID	N/A	11
4. TIME	DAYS	9
	HRS.5/MIN:6/SEC:6	17
5. SCHEDULE	TIME	27
EVENT ID	LINK	8
6. STATUS CODES	N/A	4
7. TYPE OF CHANGE	N/A	5
8. CAUSE OF CHANGE	N/A	10
9. PARAMETER ID	N/A	7
10. PERFORMANCE PARAMETER VALUE	N/A	12

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Control Concept Refinement - CASMS

CASMS MESSAGES SUGGEST SIMPLE DISPLAYS

Uncomplicated displays will support the STDN control concept.

Status Display

Within all operation control concept alternatives developed in Phase I, the initial process associated with the task of Routine Service was "assemble network resources and establish user-to-spacecraft link." The first representative display shown supports the assemblage of network resources. At the top of the display, the information contained in CASMS message category 1, Network Element Status, is displayed and highlighted in alphanumeric format. In this example, Alaska (ULA) is scheduled to support Atmospheric Explorer (AE) with link 3 on date 254 at the time 13.54. This display indicates that NASCOM, the AE POCC and ULA reported "go" for the contact at the times indicated. Since all elements have reported in prior to the scheduled contact time (and within the pre-established interval), "AE ESTABLISHED" is flashed on the display. If an element had reported a status change from green or not reported status within the interval, a highlighted indication would be displayed. This is represented by the "boxed" NAS 13.30 which would indicate that NASCOM reported "not green" for this contact at 13.30

Control Display

The second display shown is a representative Control Display. Similarly the appropriate schedule event information is highlighted at the top of the display. The events associated with the contact are delineated below. This example identified Acquisition (ACQ) and POCC Service Transaction (SERV). The time indications to the right of the abbreviations indicate the time the identified event was initiated and completed. The highlighted time after SERV indicates the scheduled contact completion time. The flashing "FIVE MINUTES" is used to exemplify the notation that operations management is "warned" of the impending contact completion time. This Operations Management has the capability to check with the POCC to determine if service extension is desired, etc., if not already announced. The final item DIS identifies the disassemblage of network resources. This is the event which constitutes the conclusion of the scheduled contact. Message category 2, EVENT MARKS, is used to supply the required display information.

Performance Parameter Display

The final display illustrates the information that would be made available when established performance thresholds are violated. Three elements of the display are highlighted. The link number (44) and time of violation

are framed at the top of the display. The performance parameter values which have exceeded predetermined thresholds and their associated values are highlighted immediately below. This example identifies signal-to-noise (S/N) ratio and bit error rate (BER). The threshold boundary violated is also flashed. The values of all performance parameters associated with that link are provided with their corresponding near, medium and long term averages (shown by x's)

REPRESENTATIVE CASMS DISPLAY

ULA 3 254.13 54 00		AE
NAS	13 45	
POC	13 46	
ULA	13 40	
NAS.	13 30	
- AE ESTABLISHED -		

REPRESENTATIVE NETWORK STATUS DISPLAY

ULA 3 254.13 54 00		AE
ACQ	13 48 00	13 53 10
SER	13 53 30	
14 09 00		
DIS.		
- FIVE MINUTES -		

REPRESENTATIVE CONTROL DISPLAY

44 -- 14 00 00		AE	
S/N	40	- RED -	
BER	10E-1		
PLL	XXX	XXX	XXX
PSE	XXX	XXX	XXX
MRK	XXX	XXX	XXX
SPC	XXX	XXX	XXX
ABC	XXX	XXX	XXX
EFG	XXX	XXX	XXX
XYZ	XXX	XXX	XXX

REPRESENTATIVE PERFORMANCE PARAMETER DISPLAY

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Control Concept Refinement - CASMS Hardware Requirements

CASMS REQUIRES DEDICATED HARDWARE

CASMS requirements can be satisfied with a sophisticated mini-computer.

CASMS Sizing Considerations

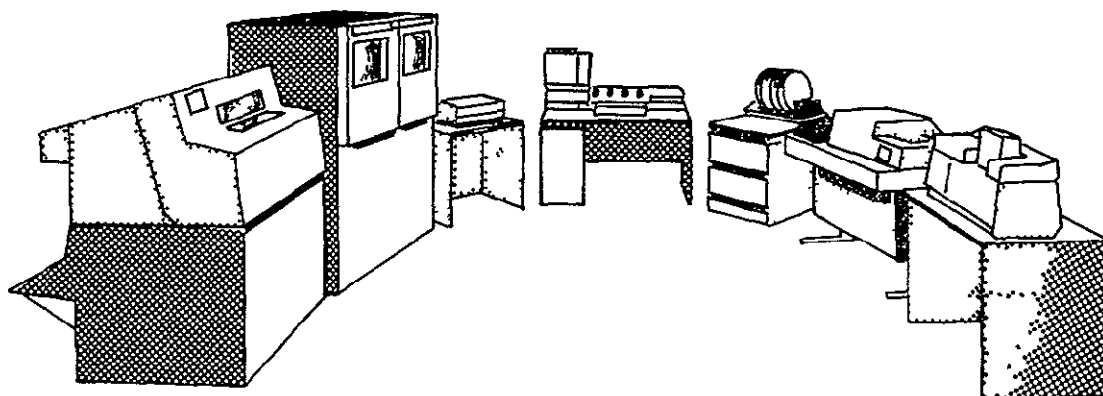
The principal parameter driving the sizing of CASMS is the maximum arrival rate of critical messages. The messages considered "critical" in the CASMS context are the performance parameter monitoring messages. They are termed "critical" because the CP interrupt carried by the arrival of a performance parameter message must be serviced before the arrival of the next such message to avoid data loss. Recalling that a 100 bit message size for CASMS was demonstrated to be more than required, and assuming that the CASMS performance parameter messages would arrive at the 9.6 kb/s rate from a maximum of 15 ground stations and NASCOM, the theoretical maximum arrival rate would be 1536 messages per second. This arrival rate would require processing a message every 650 μ sec. Allowing 100 machine cycles per message, a 6-7 μ sec machine would be sufficient. Since mini-computer operation codes execute at speeds of 1-2 μ s, a mini-computer could service the performance parameter messages. However, to ensure the fastest timing constraint is met, this operating system task would have to be continuously resident within the mini-computer CP. To accommodate the message processing tasks, background tasks such as status and control messages/displays and buffering of the performance parameters, 65K of storage has been selected. This is in addition to the nominal storage of 5-6K using core obtained with the CP. Representative of these components are the DEC 11/70, VARIAN V-76 and HPs 1MX.

Peripheral Devices

In addition to the CP and storage requirements peripherals have been selected to complement the basic CASMS system requirements. Disk and tape devices are utilized for diagnostic software, the operating system and data logging. Printer and card reader support both diagnostic and software development. Input/Output cards provide the ability to handle 8-16 external units per card.

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DEDICATED CASMS HARDWARE



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CONTROL CONCEPT REFINEMENT
—
OPERATIONS MANAGEMENT

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Control Concept Refinement - Operations Management

AREAS OF RESPONSIBILITY DEFINED FOR NOCC

The NOCC is responsible for ensuring that the functions of Network Scheduling, Network Operations, Network Service Accounting, and Network Planning are accomplished.

Introduction

During Phase I, STDN operations were segmented into four operations tasks. These tasks were stated to be scheduling, routine service, system integrity and malfunction identification, isolation, and restoration. In the Phase I context, these were the tasks or activities which the STDN had to perform in providing service to users. As such, these tasks were the operations that the control concept controlled. With the control concept defined, areas of responsibility must be assigned to STDN elements implementing the control. These areas of responsibility have been defined as Network Scheduling, Network Operations, Network Service Accounting, and Network Planning. Unfortunately, in one case - that of scheduling - the same terminology had been used to identify slightly different ideas. The following paragraphs describe each of the identified NOCC functions or areas of responsibility. These functions then form the basis upon which the NOCC workload can be defined. The following four themes trace the development of this workload in terms of subfunctions and tasks.

Network Scheduling

Network scheduling is the process by which STDN resources are allocated to users and efficient network utilization. This process is supported by the ASR algorithm previously described. The fundamental responsibilities in the NOCC are seen to be those of controlling the scheduling process, developing schedules, and participating in the resolution of conflicts when required.

Network Operations

The second function of the NOCC is to support network operations. These operations include providing real time user-spacecraft communication channels, monitoring network performance and the reaction to network degradations, and supporting the user during spacecraft emergencies.

The NOCC's responsibilities in this area include constraining network utilization consistent with the current operations control methodology, establishing and maintaining service quality standards, and ensuring rapid response to identified network operations service deficiencies.

Network Service Accounting

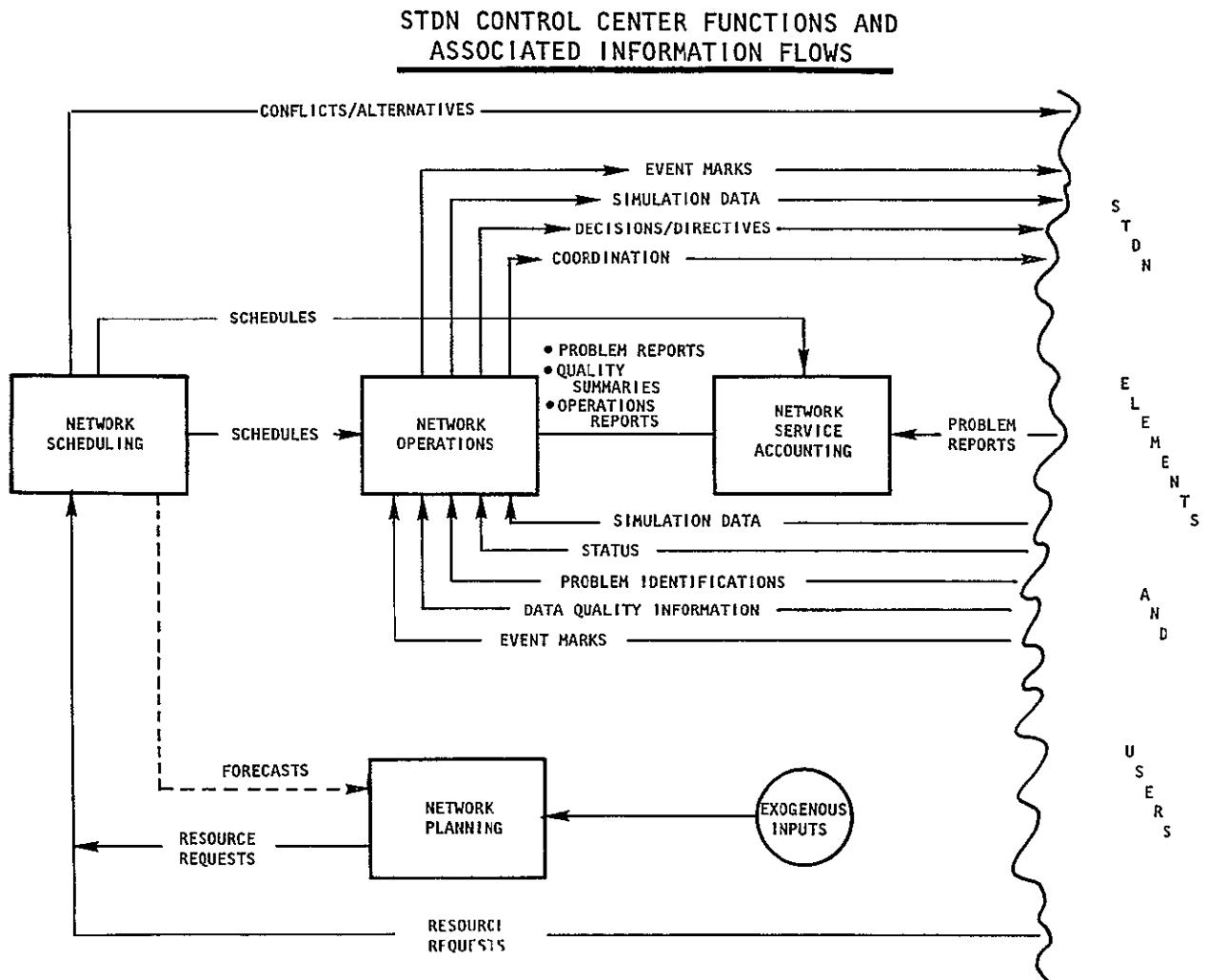
The function of Network Service Accounting provides the NOCC with a self-evaluation mechanism. This evaluation determines the extent to which the

network has met its commitment to the user. Through the use of quantitative standards, subjective evaluations are unmoved, and data is anchored for future reference purposes, as required.

Network Planning

Within this function, operations management coordinates the engineering, operational, and communications requirements in order to minimize the impact on network standards and the current requirements of other users.

Each of these functions is developed in terms of its tasks and intrafunction information flows and interfaces. Network operations will be discussed last in order to provide the foundation for the determination of routine workload staffing requirements.



Control Concept Refinement - Operations Management

NETWORK PLANNING WORKLOAD DEFINED IN THE CONTEXT OF FIVE TASKS

In its planning for STDN support of a new project, operations management coordinates the engineering, operational, and communications requirements. These activities are accomplished within the subfunctions of mission requirements verification and mission loading estimation.

Mission Requirements Verification

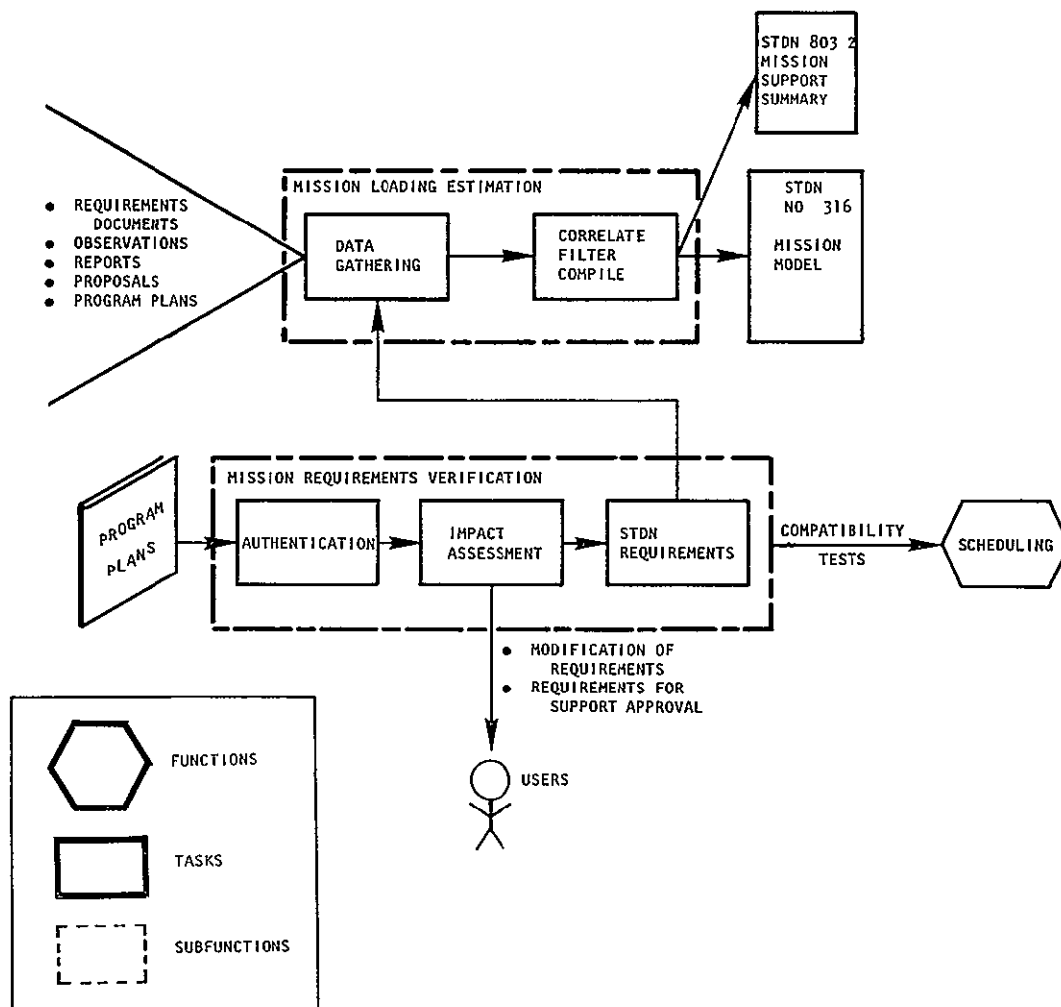
Regardless of the operation control concept alternative postulated within Phase I, a group cognizant of STDN capabilities and limitations must review the support requirements potentially placed on the network by a new project. The requirement for this review is to coordinate the engineering, operational, and communications impact of a new project in such a way as to minimize the impact on network standards and current requirements of other users.

Before network support can be committed to a project, compatibility between the user spacecraft and network resources must be demonstrated. During the 1980-1990 time frame, compatibility tests will be performed at user-designated facilities using a fully instrumented portable van and a hardware or RF interface. These tests, which will be designed by network planning as part of a task to confirm that the user data formats and the ground station hardware and software are compatible, will include both forward (command) and return (telemetry) link verification. The use of the mobile test van will permit user control centers to operate with their spacecraft, under controlled conditions, to verify support software, hardware, and procedures. During compatibility testing, magnetic tape records of spacecraft data will be generated for future use in the NOCC and as a reference data base to assist in identifying future spacecraft subsystem problems.

Mission Loading Estimation

Also inherent in the project planning function will be the development of network mission loading data designed to identify the changes in network service capability which may become necessary. As part of this activity, information from a wide range of sources, with varying degrees of "firmness", is gathered and processed. Representative outputs of this subfunction are shown in the figure.

NETWORK PLANNING TASK FLOW



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Control Concept Refinement - Operations Management

SCHEDULING WORKLOAD DEFINED IN THE CONTEXT OF 12 TASKS

The heartbeat of scheduling is defined by the tasks within the subfunction Input Processor. These tasks are, in turn, supported by those within the subfunction's Input Interrogator, Data Base Maintenance, and Distribute Output.

Input Interrogator

The two tasks within the INPUT INTERROGATOR form a preprocessor for inputs to scheduling. Herein a request is authenticated. A series of checks is performed to ensure that the request has come from a valid requestor, is in the proper format, and contains all required information. If the checks are not satisfied, a diagnostic response is sent to the DISTRIBUTE OUTPUT subfunction for transmission to the requestor. When a request is authenticated, it is routed to one of three destinations, depending upon the scheduling function's operational mode. If the request is for allocation of resources or a trial run allocation, the request is passed to the INPUT PROCESSOR. If a centralized control mode is being enforced, all resource request inputs to scheduling will be routed to DISTRIBUTE OUTPUT and, subsequently, be made available to operations management personnel in the NOCC for review. Lastly, data base queries are routed directly to the data base manager. In addition to the above actions, statistics, for example, number and type of requests by user, are derived from the preprocessor. These statistics provide a record of scheduling function utilization.

Input Processor

The INPUT PROCESSOR is the heartbeat of scheduling. When an authenticated resource request or trial run is received, its feasibility is ascertained. This feasibility analysis incorporates geometric considerations as well as time slot availability. Even though a time slot is available, NASCOM bandwidth, tracking element capability, and the like must be checked to ensure that constraint violations are not produced. If a resource request can be granted within the established constraints, the allocation is transferred to DATA BASE MAINTENANCE for data base updating. If the request cannot be granted because of resource limitations other than time availability, a diagnostic message is transmitted to the requestor via DISTRIBUTE OUTPUT. This diagnosis identifies the constraint violation and potential alternatives. If the request cannot be granted because of a time slot conflict with another user, the conflict situation is passed to the Conflict Analyzer task. If the conflict involves "generic requests", resolution is attempted within the input processor. Successful resolutions are transferred to the data base. If the conflict is beyond the capability of the conflict analyzer's resolution capability, the conflict situation is made known to the affected users and NOCC operations management personnel. Resolution is effected through a man-to-man interface with new requests being submitted to the scheduling function

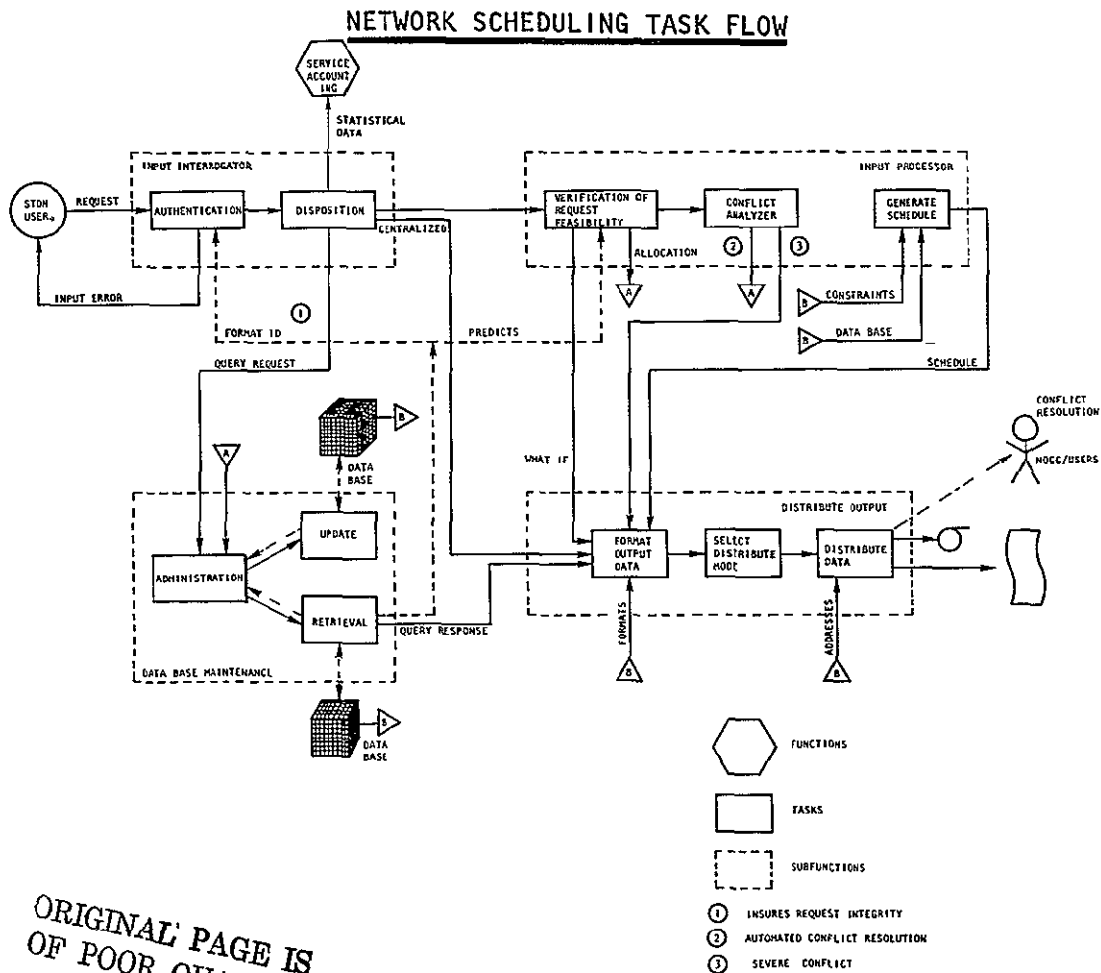
after resolution. Automated algorithm considerations for the input processor were discussed previously.

Data Base Maintenance

Under the auspices of a data base manager (administration task), updates are made to the scheduling data base, and information is retrieved and made available, via DISTRIBUTE OUTPUT, to the requestor. One of the critical aspects of the administrator is that of data base security. It is likely that all users will not be allowed to access or manipulate the data base in the same ways. Therefore, specific operational lockouts and safeguards must be incorporated within the data base manager.

Distribute Output

The tasks associated with this last subfunction are straightforward. They serve to appropriately format and distribute all scheduling function outputs.



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Control Concept Refinement - Operations Management

NETWORK SERVICE ACCOUNTING WORKLOAD DEFINED IN THE CONTEXT OF EIGHT TASKS

The tasks within the three subfunctions of Information Collection, Service Analysis, and Service Quality Documentation accomplish service accounting.

Service Accounting Requirement

Within the current operational context, there is no quantitative method by which the NOCC can establish service quality on a pass-by-pass or historical basis. Among the difficulties in establishing a measure of current performance is the fact that problems may not be reported for 6 to 8 weeks after a pass has occurred (as in the case with mailed tapes). Additionally, the NOCC must, for the most part, rely on the ground stations to establish the validity of received data. When the quantitative values (thresholds) of STDN operational parameters are established, measured parameter values received and recorded in the NOCC can be compared against thresholds thus removing a "hearsay" nature of service quality propositions.

Information Collection

The purpose of the tasks associated with the subfunction of INFORMATION COLLECTION is to acquire all relevant data for establishing a quantitative measure of STDN service quality. Since this data will be available in a time-phased fashion, it must be filtered and correlated to provide information in a useable format for SERVICE ANALYSIS. Information on magnetic tapes from CASMS and the ASR provide some of the inputs to this subfunction. It is envisioned that this information would be processed on existing-GSFC computers to provide identifications of support anomalies. When such anomalies are identified, reports relating to the cause and resolution of the anomaly would be correlated to provide the set of supporting data which is transferred to SERVICE ANALYSIS. Additionally, performance parameter summaries which establish the nominal level of service on a periodic basis would be processed in a mode similar to the anomalies to obtain service level data in a useable format for analysis and documentation.

It is critical to the overall functioning of the NOCC operational support hardware/software systems that Service Accounting Information Processing not be inserted, per se, into their requirements. The reason for this is quite straightforward. The less complicated the software, the less costly the software development, hardware integration, and potential for degradations due to overload. However, appropriately formatted outputs on tape, cards, etc. can reduce the manual data processing problems. Correlations, statistics development, and the like can then be carried in existing GSFC general service computer hardware in a batch job mode totally off-line to NOCC operationally required hardware/software systems.

Service Analysis

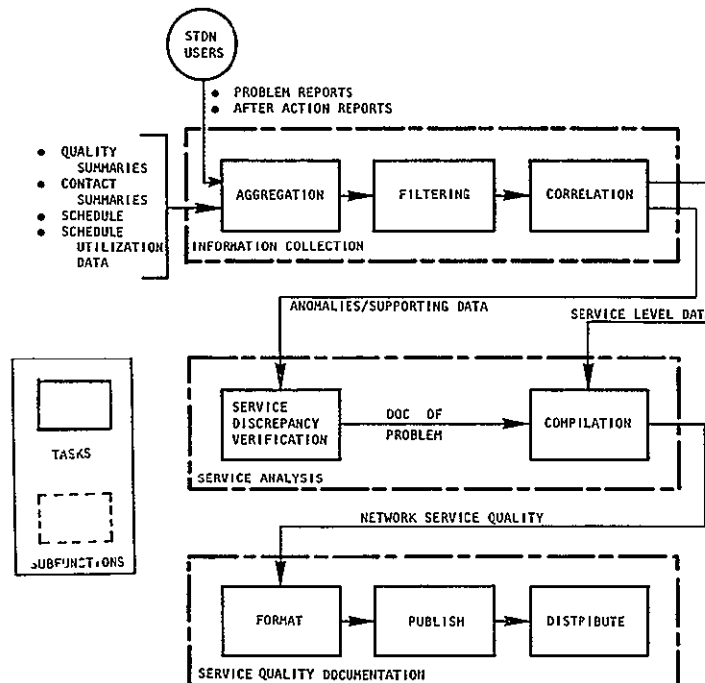
This subfunction receives anomaly identification and service level data from INFORMATION COLLECTION. The service level data essentially identifies the quality of service provided during periods which are not anomalous. The task of Service Discrepancy Verification ensures that anomalies which have been identified are completely documented. Additionally, if contradictory information is received concerning a service anomaly, it is the responsibility of the personnel performing this task to ensure that such contradictions are resolved. The second task compiles all service quality related information in a format or formats suitable for publication.

The nature of the service accounting outputs is the major factor in determining the type and nature of its inputs. The data communications industry has adapted several formats for this type of information and its display. Exploration of these formats and displays is beyond the scope of this analysis. However, these formats are designed for various purposes and levels of management, thus serving as a point of departure for establishing service accounting output formats.

Service Quality Documentation

The tasks of forming, publishing, and distributing associated with this subfunction are self-explanatory and serve to identify the formal publications process.

NETWORK SERVICE ACCOUNTING TASK FLOW




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NETWORK OPERATIONS WORKLOAD DEFINED IN THE CONTEXT OF THREE TASKS

The Phase I analysis identified four network operations tasks and, with the exception of scheduling, these translate directly into the subfunctions of System Integrity, Malfunctions, and Routine Service.

System Integrity

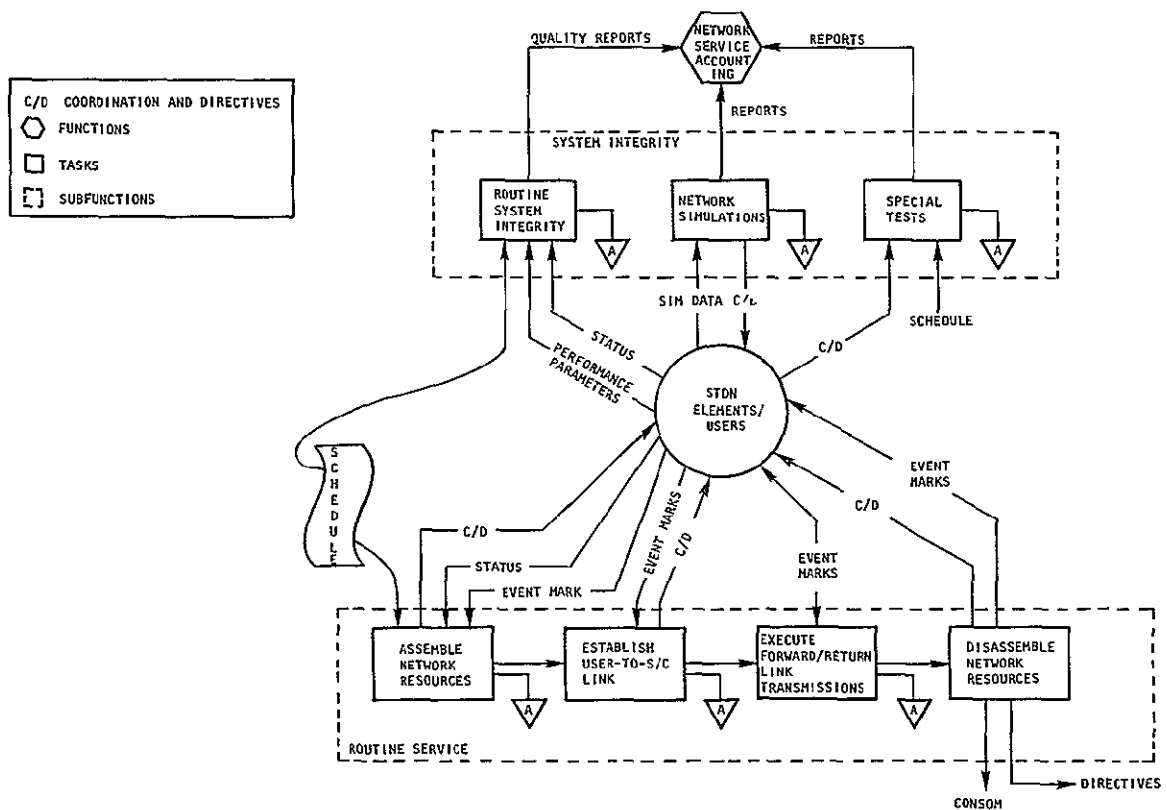
SYSTEM INTEGRITY is the process by which network operations management ensures that STDN elements are capable of performing to established standards. The task of Routine System Integrity is to provide real time estimates of STDN service quality. The task Network Simulations serves to establish STDN or combined STDN-user performance capabilities prior to an actual want. Special tests establish performance standards for new and/or existing hardware and software. As shown, these tasks function on a relatively independent basis. However, since all tasks may identify malfunctions, each has a branch to that subfunction as designated by  in the figure.

Malfunctions

When problems are identified, the first step in the restoration process is the verification that a problem does in fact, exist. A technical support team assists the NOCC in problem isolation as required. This process could involve analysis of detailed CASMS performance parameter history data. Assistance from all elements involved in the problem is enlisted. This is indicated in the figure by the query-response (Q/R) interaction between the task of Isolation and the STDN elements/users. For severe problems, special tests or simulations may be required to affect isolation. Restoration involves a free form or ad hoc activity in which actions for problem alleviations are identified and implemented.

Operational problems may be identified in the NOCC, the ground stations (TDRSS/GSTDN), POCC, or experimenter centers. Operations in the TDRSS era place special requirements upon all STDN users with regard to the MALFUNCTION tasks. The most critical requirement is judged to be in the area of procedures/language. In the case of multimegabit users (e.g., SEASAT), data is to be transferred directly to the "experimenter". Needless to say, a spacecraft tape dump does not necessarily present data in a precise manner! Contrastingly, some users can accept "jiggles" in data and correct for these occurrences. As a result, the definition of problems must be explicit in the TDRSS-era. Statements of "I'm getting garbage" will not assist in solving a real time data transmission problem. More explicit problem identification must be made. For example, statements similar to "frames 101 - 852 lost", the bit error rate has succeeded 10^{-3} ", etc. will prove more effective in problem isolation activities.

NETWORK OPERATIONS TASK FLOW

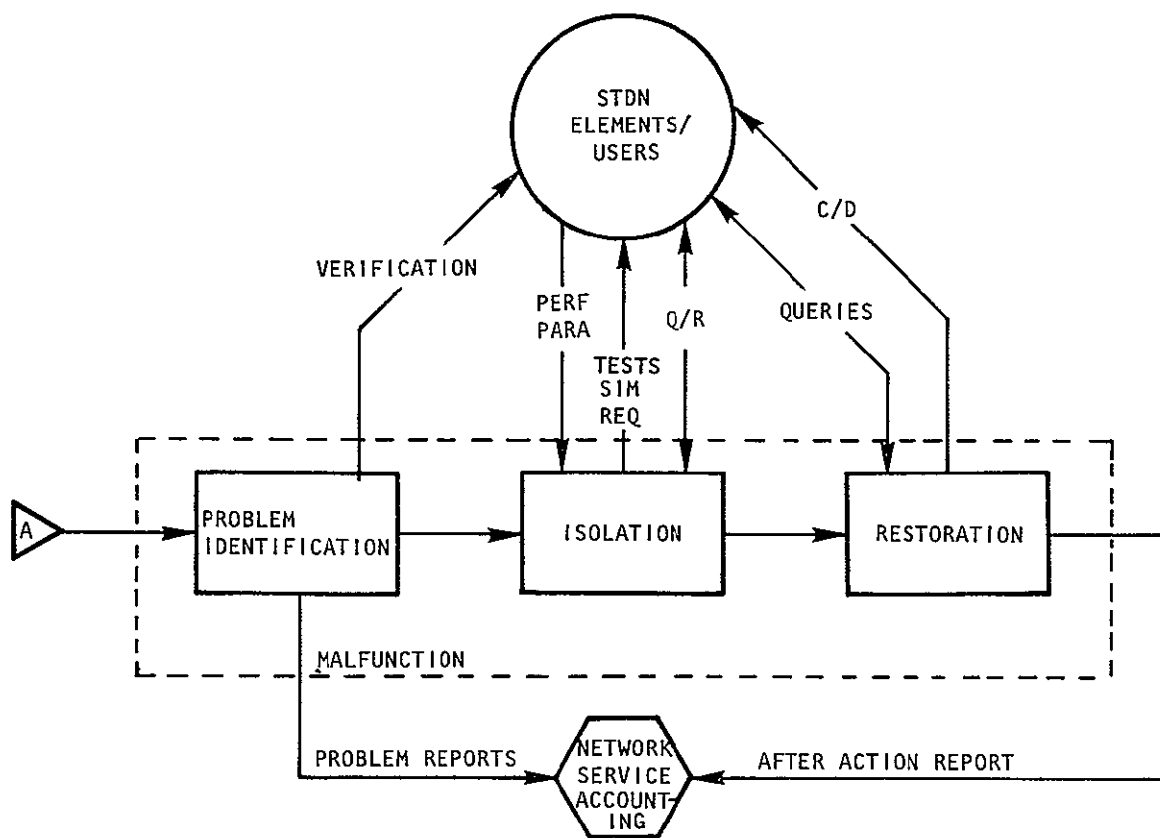


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Routine Service

The tasks associated with routine service form the basic workload for the STDN control center. Execution of a contact is envisioned to occur in the following manner. On a preestablished basis, such as from a hardcopy of a schedule, the network controller (NC) knows a contact he is to manage is about to occur. At a predetermined interval, the NC accesses CASMS to obtain a status display monitor to that shown previously. If all network elements are "go" for the contact, the NC initiates a computer-generated message to the appropriate ground station (TDRSS or GSTDN) to initiate the acquisition sequence and calls the CASMS control display. Upon completion of the acquisition sequence, the ground station issues an event mark which is registered on the CASMS control display. If no Status Change messages affecting the STDN elements involved with the contact have been received, the NC signals the POCC/experimenter that a spacecraft link has been established. At the completion of the POCC/experimenter-spacecraft contact, the NC is signaled with an event mark message. The NC then issues an event-completed message to the network elements and files a contact summary report with CASMS.

NETWORK OPERATIONS TASK FLOW



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SCHEDULED EVENT OCCURRENCE RATE DETERMINES ROUTINE WORKLOAD

The TDRSS Planning Mission Model provides the basis for a relationship between requested support and network routine workload.

TDRSS Loading

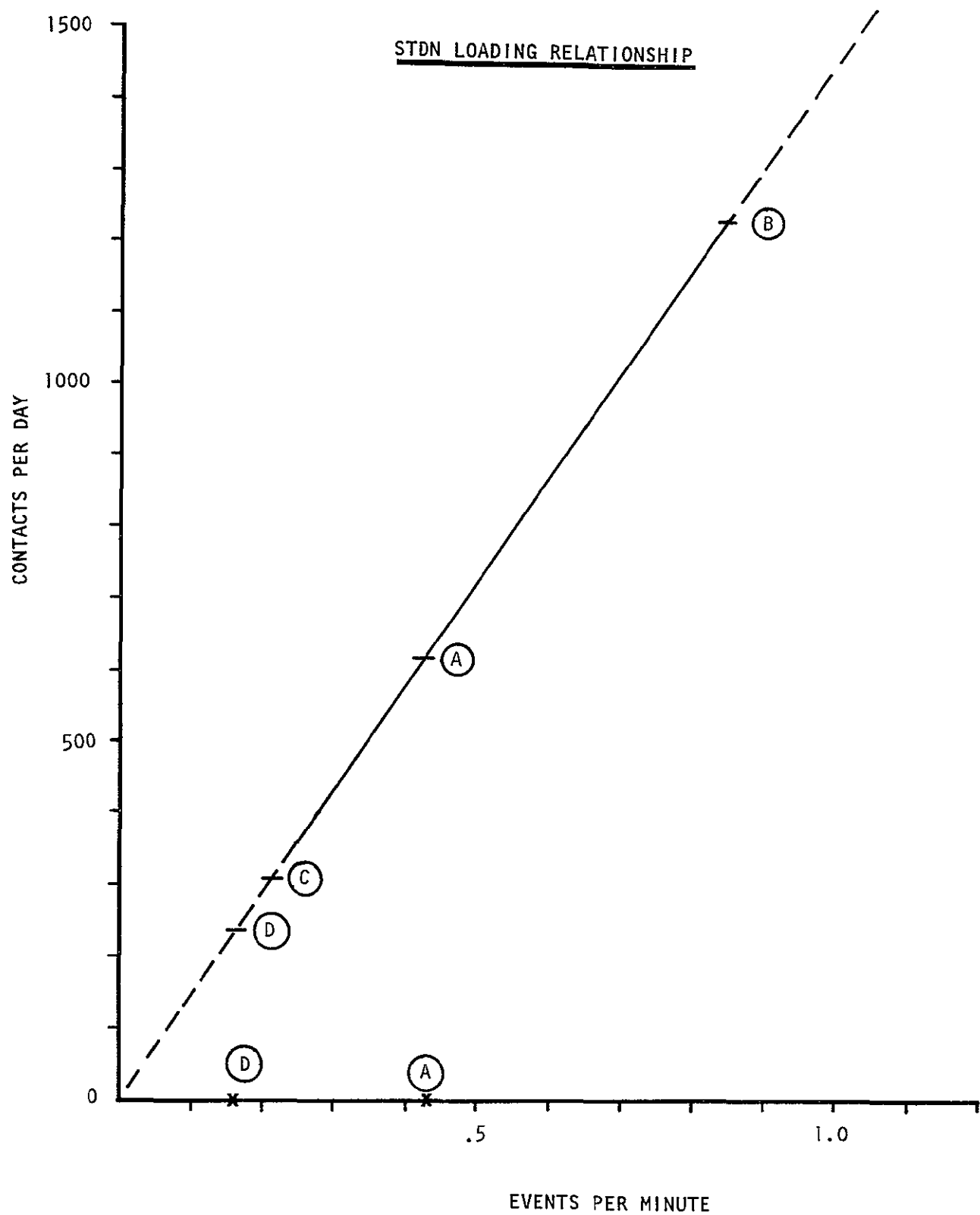
The data provided in the TDRSS Planning Mission Model (Reference 1) suggests a TDRSS baseline load of approximately 620 contacts per day. This point is identified as (A) on the figure. If a uniform distribution of these events is postulated, approximately .4 events (contacts) occur every minute. This equates to an event, or contact, occurring every 2-1/2 minutes. As described in the Phase I Report TDRSS Operations Control Analysis Study (Reference 18), the mission model data served as a basis for increasing loads to 100 percent of the baseline and decreasing support requirements to 50 percent of the baseline load (points (B) and (C), respectively). In general, for the specific mission classes and support identified in the planning mission model, the figure shown describes the rate of contact occurrence for any load (described by the dashed lines).

GSTDN Loading

The same mission model identifies expected GSTDN loading. Due to the difficulty in translating the stated support requirements into contacts per day, certain assumptions were required. As a worse case, it was assumed that GSTDN supported satellites required either one or two contacts every 90 minutes, or approximately 15 contacts per day. If contacts with some satellites are longer or continuous, it serves only to decrease the number of contacts and, hence, the NOCC routine workload. Thus, under the above assumption for contacts, a baseline workload for GSTDN was established at 240 contacts per day or one GSTDN event every 5 minutes. This is represented by (D) in the figure.

The preceding event rates will serve as a baseline routine network workload for the subsequent staffing analysis.

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SYSTEM "SETUP AND TEARDOWN" ARE THE ROUTINE TASKS

The duration of time required to manage "setup", prior to a contact, and "teardown", subsequent to a contact, and the rate in which events are arriving at the NOCC determine the number of simultaneous routine activities.

Task Description

As previously noted in the discussion on Routine Service, the STDN control center or, more precisely, the network controller has a series of tasks to perform in the normal execution of any contact. Simply, the network controller is responsible for assembling the network elements prior to a transaction and teardown subsequent to a transaction. To accomplish these tasks, the controller must first have a preestablished knowledge of the event, check network element status via CASMS, generate messages to TDRSS or GSTDN to initiate the acquisition process, check CASMS for the completion of acquisition and current network status, signal the POCC that the network is "go" for the transaction, and notify elements of transaction completeness.

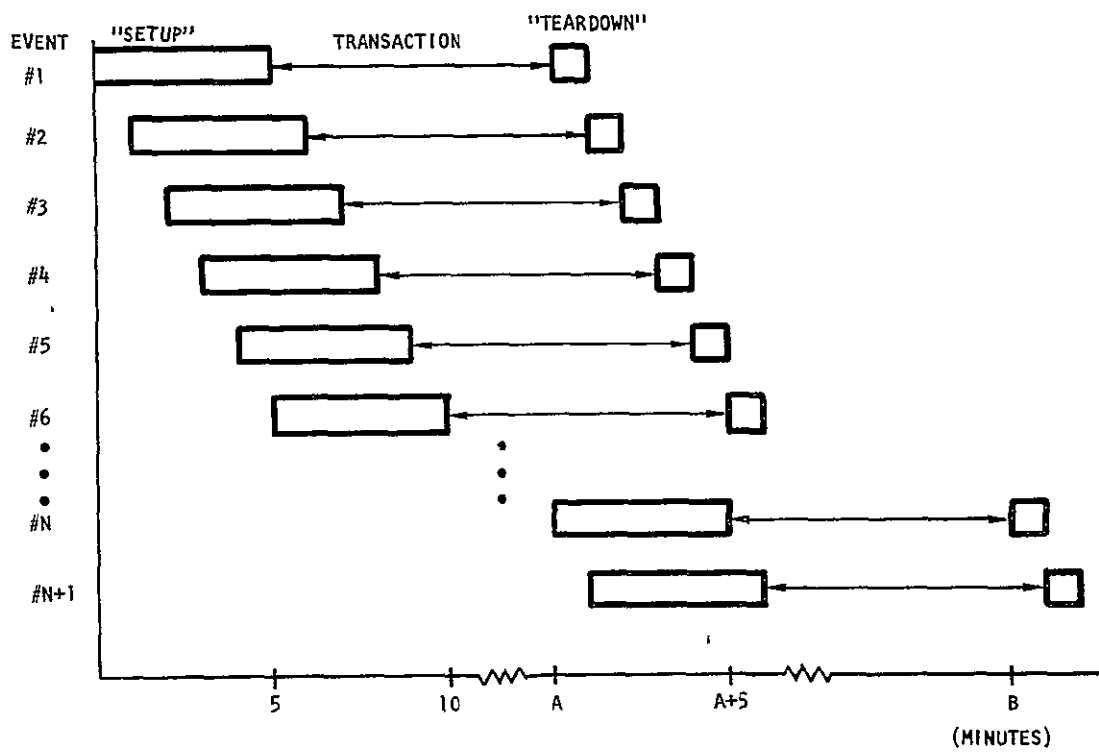
Speed and Event Arrival Rate

The speed in which the controller can accomplish these tasks will affect the probability that a second or subsequent event will occur during the critical sequence of network assembly/disassembly. Speed dictates the duration of cognizant time the network operator must give to that particular event. Once the transaction begins, however, the controller has little responsibility until completion, at which time teardown of the system must be accomplished. Coupled with speed is the rate of event arrival in determining simultaneous events. The faster the arrival rate, the greater the probability of simultaneous events.

These two effects are portrayed in the facing illustration. Network assembly is assumed to be 5 minutes in duration, disassembly, 1 minute, and arrival rate, one contact per minute. As depicted, this results in six simultaneous "setup" events to be accounted for at any instant of time. Since the network controller is not responsible for the event during the transaction, this period is essentially free time. The case illustrated is an optimistic example since transaction times are equivalent for all events. Here, only two additional events can occur simultaneously because of the "teardown" time. This is seen as the Nth event starts, as the first event initiates "teardown", and the N+1st event starts as the first event completes the "teardown". Thus, for the case in which assembly requires 5 minutes and disassembly requires 1 minute, the rate of event and transaction times are constant, and arrival is one per minute. Eight simultaneous events can occur.

For purposes of analysis, "teardown" was assumed to be 1 minute and transaction time constant as assembly time and event arrival rate varied

DERIVATION OF SIMULTANEOUS EVENTS



Control Concept Refinement - Operations Management

MANPOWER REQUIREMENTS

Quantitative relationships between loading and simultaneous events determine required NOCC console positions.

Factor Interdependencies

The number of console operators required to adequately absorb the workload for 24 hours a day, 7 days a week, 52 weeks a year is a direct function of the number of console positions to be manned. The number of console positions to be manned, in turn, is a function of the system loading, time required for network assembly for each contact, and the individual operator's ability to handle a given number of simultaneous events over a given length of time. The facing illustration depicts the interdependencies of these factors and how they dictate required console positions. The following example illustrates the use of the exhibit and procedure for calculating the required console positions.

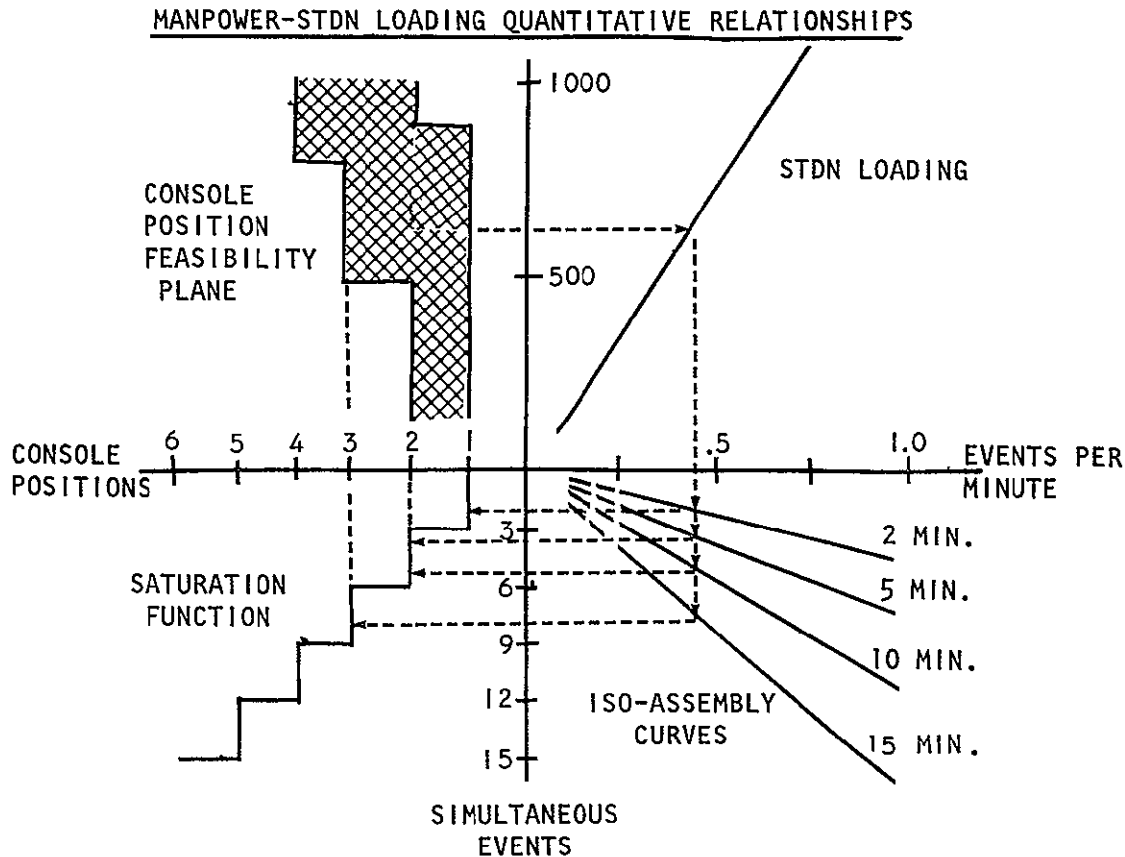
Requirement Calculation

Starting in the northeast corner, the STDN Loading Function reflects the straightforward positive relationship between the number of contacts per day and the rate in which events are arriving at the NOCC. The dotted line from the vertical axis indicates a level of approximately 620 contacts per day, corresponding to the TDRSS baseline loading. This translates into an arrival rate of .43 events per minute at the NOCC. Therefore, on the average, events will be initiated every 2.3 minutes.

The time required to assemble the network, given the rate in which events are arriving, will then dictate the number of simultaneous events, on the average, to be accounted for at any instant of time. This relationship is illustrated in the southeast corner of the exhibit by the Iso-Assembly Curves. Along each curve, the length of time required for assembly is held constant. Assumed for each curve is a constant 1-minute disassembly time. Each event is assumed to occupy the operator until network assembly is completed. At this time, the network is turned over to the POCC for the transaction. The operator in the NOCC is not required again until network disassembly is required at the completion of the transaction. Thus, from the NOCC operator loading viewpoint, the transaction time is not a critical factor in operator workload. Therefore, the number of simultaneous events to be accounted for is driven by the length of assembly time. Note, the dotted lines of the Iso-Assembly Curves are extrapolations while the solid lines are calculated from the NASA Mission model. In our example, an event rate of arrival of .43 translates into approximately 2.1 simultaneous events to be tracked at an assembly time of 2 minutes, 3.4 events, at 5 minutes, 5.6, at 10 minutes; and 7.7, at 15 minutes. Given the simplistic and routine nature of network assembly, BDM feels that 5 minutes for assembly is a reasonable approximation. Therefore, the number of simultaneous events occurring at any instant of time will be about 4, on the average.

In the southwest corner of the exhibit, a saturation function is presented. This function illustrates the relationship between the number of simultaneous events occurring at any instant and the required number of console positions required. This function was derived based upon information from human factors experts participating in the study as well as extrapolations of existing bioengineering and related data (References 6, 7, 8). Thus, the relationship is a step function indicating three simultaneous events per console position required.

In the northwest corner of the exhibit, the relationship between the required console positions and the number of contacts is illustrated via a Console Position Feasibility Plane. Here the maximum number of console positions required reflects the stepped saturation function as the bottom of the plane "steps up" as contacts increase. The minimum number, however, is driven by the 2-minute assembly time. Here it can be seen, for the relevant range of the STDN Loading Function, that events arrive at a rate of less than one every minute. Therefore, for the 2-minute assembly time (and initiated by 460 contacts), there are always less than six simultaneous events occurring at any instant, translating into a console position requirement of not greater than two and, thus, explaining the "one stepped" top of the plane. The feasibility plane provides the maximum and minimum required console positions for any loading factor, given the assembly time and saturation function. For the TDRSS baseline case and an assembly time of 5 minutes, two console operators are required. Note that the GSTDN requirements can be found in a similar fashion, given the predicted number of contacts to be processed by the NOCC.



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MANPOWER REQUIREMENTS

Saturation Sensitivity

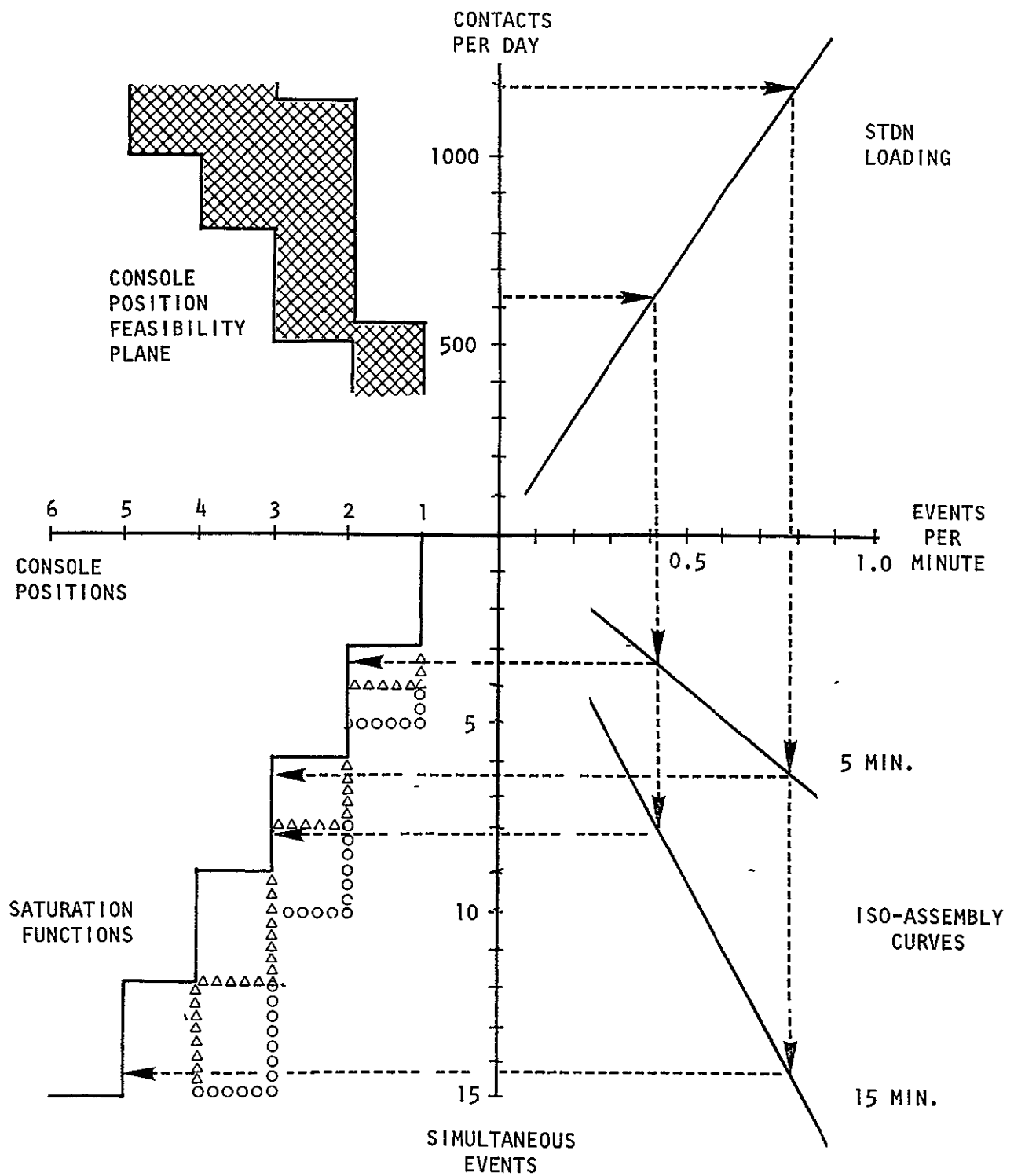
Just as the sensitivity of network controllers positions to assembly time was illustrated, a similar analysis can be implemented for the Saturation functions employing the four-quadrant diagram provided. For the analysis, baseline and approximately two times the baseline (1200 contacts) loading are used along with network assembly times of 5 and 15 minutes. In the facing diagram, the changes in the Saturation Function are depicted by overlays of circles (o) and triangles (Δ), for the new levels of saturation. The circles represent five simultaneous events now being handled satisfactorily before degradation begins, while the triangles represent four events. As seen, circles are found at the 5, 10, and 15 simultaneous event levels and triangles at the 4, 8, and 12 event levels.

For the TDRSS baseline and the BDM suggested assembly time of 5 minutes, it will take two controller positions to handle the workload, given the capability of handling three simultaneous events. However it will require only one position if a level of four or five simultaneous events can be handled. Doubling the baseline load will result in an increased requirement to three console positions for a saturation function of three simultaneous events, while requiring two positions for functions of four and five events. At an assembly time of 15 minutes, the effects of varying the saturation function became more important. At the baseline, an assembly time of 15 minutes dictates the requirement of three console positions for a saturation function of three simultaneous events, and three are required for four simultaneous events, while 2 are required for five simultaneous events. Doubling the load with an assembly time of 15 minutes indicates a requirement for five console positions for three simultaneous events, four console positions for four simultaneous events, and three console positions for five simultaneous events. The Console Position Feasibility Plane reflects a three simultaneous event Saturation Function and a minimum assembly time of 5 minutes.

Principal Control Concept

In the Principal Control Concept, an assembly time of 5 minutes and a saturation function of three simultaneous events were employed. Thus, for the TDRSS baseline mission model and GSTDN estimates (860 contacts per day), three network controller positions are required.

MANPOWER-STDN LOADING QUANTITATIVE RELATIONSHIPS



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Control Concept Refinement - Operations Management

NOCC STAFFING ESTIMATED FOR PRINCIPAL CONTROL CONCEPT

A total of between 25 and 55 personnel can conduct and support NOCC operations.

INTRODUCTION

The console position feasibility plane was utilized as the basis for staffing requirements where the number of required positions was load dependent. However, most positions identified on the opposite page are not significantly affected by load. In these instances, history, intuitive judgment, and related experience have been applied to establish console position requirements. To determine the actual individual staffing requirements, the following scheme was employed. A position which is staffed 24 hours a day, 7 days a week, 52 weeks a year requires manning 8736 hours a year. It was assumed that one man will work 50 weeks a year (with 2 weeks of vacation), 40 hours a week, and receive nine federal holidays paid leave per year. Thus, one man will provide 1928 hours of work a year. These five people provide a total of 9640 hours for an 8760-hour year. The additional hours are assumed to cover sick leave and other absences from work. Therefore, a total of five people will be required to staff one position continuously. Requirements for people for one shift, 5 days a week, were considered to be positions with manning requirements for 2000 hours. These positions were assumed not to be staffed for 2 weeks of vacation per year. During this time, required work would be either forced to wait or absorbed by associated staff members.

Network Controllers

Network Controller (NC) position requirements were determined from the position feasibility plane utilizing an assembly time of 5 minutes. Additionally, the GSTDN and TDRSS loads were considered independently to allow for any potential special NC activities that may be associated with GSTDN or TDRSS operations. Since the loading on all controllers is not near the limit of these continuous simultaneous activities, at the end of 1-1/2 hours one NC could take a short break while the others absorb his activities. For the positions indicated, which are staffed 24 hours a day every day of the year, 15 people are required. The activities carried out by the network controller are basically the set up and turn down of the network in support of routine service and network simulations. In this capacity, the NC utilizes CASMS to determine STDN element status and the progress of activities for which he is responsible. When anomalies in status or service occur, the NC is responsible for ascertaining whether the anomaly will impact the current schedule or not. If it does, resolution of the situation is referred to the Operations Manager and Systems Analysts.

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Operations Support

The operations support team includes those positions shown. Each position, in this case, translates directly to people since all positions were defined on a 40-hour week, 2000-hour year basis. The Technical Support Group is responsible for providing technical and operations systems support to the NOCC and STDN as required. Documentation and programmer support is provided for the control/dissemination of procedural changes and software development/modification, respectively. The planners are responsible for evaluating future user requirements for their potential support in network support capability. Additionally, feasibility of support is determined. The four positions correspond to user spacecraft categories of communications, weather, space investigation, and miscellaneous. Service accountants ensure that network element service quality is documented and achieved and that identified service degradations resolution is recorded.

Estimates on the number of positions and staffing requirements are based on informal discussions with satellite communications companies, GSFC Network Operations Division personnel, and related experience.

OPERATIONS AREA STAFFING ESTIMATES



TDRSS



NETWORK
CONTROLLERS

GSTDN



STDN



SYSTEMS
ANALYSTS

CASMS/ASR



OPERATIONS
MANAGER



SCHEDULERS



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NOCC STAFFING ESTIMATED FOR PRINCIPAL CONTROL CONCEPT

Systems Analysts

Two systems analyst positions have been defined. The first position, STDN Systems Analyst, is responsible for providing technical and operational support to the NOCC and STDN. This position serves as the focus for technical information, observations, and suggestions relating to network operation. It also provides assistance required by the network in the maintenance of existing equipment.

The second position, CASMS/ASR Systems Analyst, provides detailed working knowledge of the software/hardware systems supporting the NOCC. As staff to the Operations Manager, this individual has a detailed understanding of the ASR/CASMS algorithms, their capabilities, and their limitations. This analyst has the capability to determine proper ASR algorithms to be used, determines the point of diminishing returns for algorithms being used, and assists in formulating network problems in terms that will allow the ASR to be used as a tool. Since the requirements on these positions are entirely situation dependent, at least one full-time analyst position has been assumed.

Schedulers

One to two scheduler positions have been identified for the NOCC. These positions support the Operations Manager (OM) by providing the direct interface to the ASR. The schedulers ensure that conflicts are brought to the attention of the Operations Manager. These individuals are responsible for . . . executing trial ASR runs for the OM, operating peripheral ADP equipment, inserting ASR operating constraints, etc. The positional requirements are based on a qualitative estimate of this workload.

Operations Manager

The position of Operations Manager is staffed with an individual who is authorized and responsible for the overall control and efficient technical operation of the STDN. He has detailed knowledge and understanding of the impacts of network element malfunctions. The OM is the focal point for all conflict and problem resolutions. A single position has been assigned to this function. It should be noted that for special activities, such as launch, it is envisioned that the OM staff is augmented. The requirement for another OM may be dictated by the operation situation. However, as the basis for operations control alone, the requirement for a special individual, such as the current Network Director, to conduct special activities can not be supported.

SUPPORT AREA STAFFING ESTIMATES



TSG



DOCUMENTATION



PROGRAMMER



PLANNING



SERVICE
ACCOUNTANTS

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FIVE MAJOR SKILL LEVELS REQUIRED IN NOCC

The operation of the NOCC requires a mix of five generic skill levels to successfully accomplish the tasks just identified.

Introduction

The following paragraphs discuss the five major skill levels which have been identified to support NOCC operations for the operations control alternatives identified in Phase I. For each skill level the general performance capabilities of an individual within the level is identified. Subsequently, the generic job requirements for oral expression, written expression, comprehension of written material, mathematical computation and responsibility for independent action are identified. It should be kept in mind that these requirements are not unique to the skill level to which associated. Instead they represent the requirements that could most likely be associated with the skill level.

Skill Level 1

This level identifies helper or entry level positions requiring performance of simple tasks under general supervision, or performing more difficult tasks under close supervision. At this level personnel must be capable of discussing simple facts, routine operations or instructions using common words or trade terms. Written work is standardized and little creative writing is required. They must comprehend simple and brief facts or instructions involving common technical terms and/or specifications, charts, drawings, or tables in common use. Addition, subtraction, multiplication or division is the highest level of mathematical ability required. The position requires conformance to standing procedures with little or no requirement for independent action.

Skill Level 2

Positions requiring performance of difficult tasks under general supervision are grouped in this skill level. This level represents a fully qualified, or journeyman level, of nonsupervisory skill. They must discuss or instruct others in a variety of job operations frequently using specialized terminology. Writing may be a significant aspect of jobs requiring moderate capability to organize and clearly present ideas, concepts or research findings using technical terminology when required. This skill level may require computation using algebra, plane geometry, trigonometry or simple statistical formula. Individuals in this skill level have responsibility for making minor modifications in procedures to adapt to the particular situation.

Skill Level 3

Skill level 3 identifies positions requiring performance of tasks that are significantly different from, and in addition to, tasks performed at skill level 2 that require a minimum of supervision. This represents the advanced journeyman level of nonsupervisory skill. This level requires an oral capability to discuss or instruct in complex information and ideas, using terminology and phrasing that is primarily technical, professional or specialized. Writing may be an important aspect of the job in this skill level, thus requiring either an unusual ability to present complex ideas in non-technical language, or ability to prepare technical articles at a level comparable to standards imposed for publication in professional scientific journals.

Skill Level 4

First line supervisory positions that require relatively detailed knowledge of the tasks performed by subordinate personnel are classed as skill level 4. This level will imply a facility with technical terminology. Jobs in this level may involve discussion or instruction in advanced phases of subjects requiring a significant capability to present abstract ideas orally. Advanced mathematical processes such as differential equations or vector analysis should be understood. Work is performed independently throughout except for initial assignment of an end goal (which may be self-initiated), and work is subject to review only in terms of results obtained.

Skill Level 5

The final skill level identifies higher level, managerial-type supervisory positions that require a broad, general knowledge of the tasks performed at all subordinate levels.

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NOCC REQUIREMENTS SUMMARIZED

The matrix of tasks, information elements, hardware/software systems, skill levels and responsibility establishes the STDN control center concept.

Overview

The purpose of the matrix is to: 1) identify second level message definitions and information requirements on a task-by-task basis, 2) correlate tasks and NOCC hardware/software systems, 3) relate the tasks to skill level requirements, 4) assign task responsibility to NOCC staff positions, and 5) identify the NOCC man/machine interfaces. The left side of the matrix identifies the NOCC functions, subfunctions and tasks that have been discussed earlier in this section. The elements at the top of the matrix will be discussed in the following paragraphs.

Message Definitions

Phase I identified 11 generic classes of information required to support the operational control alternatives. These classes were: Status, Event Marks, Requests, Constraints, Conflicts and Alternatives, Directives/Coordination, Performance Parameters, Data, Problem Identifications, Problem Reports and Orbital Support Data. Where necessary to support control concept refinement, these message categories have been developed into message types. Additionally, message classes and types have been added to support intra NOCC information requirements. The "X"s in the matrix identify the information required by each task.

Correlation to Hardware/Software Systems

Each of the tasks within the operational control system must be performed by a man, a machine or a man/machine interface. The circles in the matrix correlate the tasks and the method by which they are accomplished. Solid circles (●) identify those tasks which are accomplished totally by a single method. For example, malfunction restoration is inducted as a totally manual process. Open circles (○) identify the tasks which are machine supported. These open circles identify man/machine interfaces. The term "other" is used to identify data processing systems other than ASRU CASMS resident at GSFC.

Skill Level Requirements

The third element of the matrix relates the tasks to skill level capabilities and the tool requirements for each skill level. The skill levels are indicated by numbers which reference the skill levels just previously defined.

SUMMARY OF NOCC REQUIREMENTS

FUNCTION	SUBFUNCTION	TASK																												
			DATA STATUS	FILE STATUS	TRAN STATUS	ADJ STATUS	STOR STATUS	ENTR STATUS	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	ENTR CORR	
NETWORK OPERATIONS	ROUTINE SERVICE	ASSEMBLE NET RES EST USER TO S/C LINK EX TWO/PATH LINK DISASSEMBLE NET RES	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	MAINTENANCE	IDENTIFICATION ASSOCIATION REASSOCIATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	SYSTEM INTEGRITY	ROUTINE SYS INTEGRITY NET SIMULATIONS SPECIAL TESTS	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
NETWORK SCHEDULING	INPUT INTERPOLATION	AUTHENTICATION DISPOSITION																												
	INPUT PROCESSOR	VER REQ FEASIBILITY CONFLICT ANALYZER CONFLICT RESOLUTION GENERATE SCHEDULE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	DATA BASE MANAGEMENT	ADMINISTRATION UPDATE RETRIEVAL																												
	OUTPUT DISTRIBUTION	FORMAT OUTPUT DATA SELECT DIST MODE DISTRIBUTE																												
NETWORK SERVICE ANALYSIS	INFORMATION COLLECTION	AGGREGATION FILTERING																												
	SERVICE ANALYSIS	CORRELATION SERV DISCREPANCY VER																												
	SERVICE DOCUMENTATION	AGGREGATE INFO FORMAT PUBLISH DISTRIBUTE																												
NETWORK PLANNING	MISSION COORDINATION ESTIMATION	DATA GATHERING CORREL FILE COMPILE																												
	MISSION REQUIREMENTS VERIFICATION	AUTHENTICATION IMPACT ASSESSMENT STOR REQUIREMENTS																												

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Responsibility

The last column in the matrix establishes the responsibility for task accomplishment on the basis of NOCC positions previously defined. In this column the following abbreviations are used Network Controller (NC), STDN Systems Analyst (SSA), CASMS/ASR Systems Analyst (CSA), Schedulers (SC), Operations Manager (OM), Technical Support Group (TSG), Service Accountants (SA), Planners (PN).

Matrix Utilization

The facing exhibit illustrates the correlation of required information, man/ machine interface, and skill level needed to provide a logical and complete description of personnel responsibilities for operations and support tasks. For example, operations management has been identified as having the responsibility to restore malfunctions, resolve scheduling conflicts, and coordinate special events such as simulations and tests. In satisfying the latter two tasks, he is required to interface with ASR and CASMS respectively, while the nature of system restoration dictates a manual process. For special events he will require status information, scheduling data, and performance parameters to ensure successful completion of the simulation or test. While in the process to resolve scheduling conflicts, operations management will require information on the requests, all constraints, and possible alternatives. As indicated, ASR will provide the bulk of this data. In restoring network elements, which are temporarily out of service, he will need impact on current status changes, performance parameters and additional information provided by the network elements.

In addition to these operationally oriented tasks, the operations manager is responsible for the day-to-day operations of the NOCC. All of these tasks require a management skill level as indicated (Skill Level 4-5)

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Control Concept Refinement - Operations Management

IMPACT OF ALTERNATIVE CONTROL CONCEPT/LOAD VARIATIONS

Variation to the Principal Control Concept and Loading will impact the personnel and hardware requirements of the NOCC/network.

Principal Control Concept

As previously delineated, the Principal Control Concept requires the personnel support of network controllers, system analysts, schedulers, operations management, and operations support. Varying the control concept alters the responsibility of an operational function and impacts the allocation of personnel resources. In addition, changing the loading factors will directly affect the personnel requirement no matter what control concept is employed.

For the Principal Control Concept the NOCC Operations required three network controllers positions (5 personnel per position), two scheduler positions, two systems analyst positions and one operations management position. In support of the operations a five member technical support team, a four member planning group, a four member service accounting group, and one person for documentation and another for programming were identified.

The facing table displays the control concept alternatives with major personnel/hardware changes from the baseline Principal Control Concept given the mission loading.

Alternatives

Centralized Scheduling

Centralized Scheduling requires the NOCC to monitor all requests from the sensors, both formal scheduling and "what ifs." Monitoring can range from a format and content check to an intercept, aggregate, analyze and resubmit function. BDM estimates are based on the latter, with the resulting increase in position requirements of one to two (costing estimates one based on an increase of two positions).

Decentralized Scheduling

There is no appreciable change in requirement, although conflict resolution is now decentralized and must be absorbed by the elements/users.

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Matrix Scheduling

In accordance with the Matrix Scheduling Concept, the responsibility of scheduling all network element maintenance falls in the review of the NOCC. The result is an increased requirement for one scheduler (one shift) to handle this function.

A second approach to Matrix Scheduling is to centralize the maintenance and non-GSFC POCC scheduling. The study team estimated that the effort of such a concept would increase the requirement for scheduling by one position.

Centralized Routine Service

By centralizing routine service no appreciable change in requirements results.

Decentralized Routine Service

In decentralizing service the POCCs will be required to assemble the network for contacts. This results in a reduction in the NOCC of network controllers to one position operating in a back-up mode. To the POCCs this concept requires hardware modifications in terms of terminals for CASMS access and possibly an increase in personnel.

IMPACT OF ALTERNATIVE CONTROL CONCEPT/LOAD VARIATIONS

CONTROL CONCEPT	CHANGES IMPACTING COST			COMMENTS
	BASLINE MISSION	100% INCREASE	50% REDUCTION	
PRINCIPAL	3 CONTROLLER POSITIONS 2 SCHEDULE POSITIONS	2 ADDITIONAL NC'S AND SCHED POSI- TIONS	2 CONSOLE POSITIONS 1 SCHEDULER POSITION	CONFLICT RESOLUTION DECENTRALIZED ADDITIONAL FUNCTIONS MUST BE ABSORBED BY ELEMENTS/USERS
CENTRALIZED SCHEDULING	1-2 INCREASE IN SCHEDULING POSITION	1-2 INCREASE IN SCHEDULING POSITION	INCREASE OF 1 SCHEDULING POSITON	
DECENTRALIZED SCHEDULING	NONE	NONE	NONE	
MATRIX SCHEDULING (CENTRALIZED MAINTENANCE SCHEDULING)	1 EXTRA SCHEDULER 1 SHIFT	1 EXTRA SCHEDULER 1 SHIFT	1 EXTRA SCHEDULER 1 SHIFT	
MATRIX SCHEDULING (CENT MAIN/NON-GSFC POCC SCHEDULING)	1 EXTRA SCHEDULING POSITION	1 EXTRA SCHEDULING POSITION	1 EXTRA SCHEDULING POSITION	SET UP IS CENTRALIZED AND IS MAJOR PART OF WORKLOAD ADDITIONAL POCC PERSONNEL NOT COSTED TO ACCESS EITHER CASMS OR ASR, NETWORK CAPABLE PEOPLE IN POCC/USER
CENTRALIZED ROUTINE SERVICE	NONE	NONE	NONE	
DECENTRALIZED ROUTINE SERVICE	REDUCE TO 1 CONSOLE POSITION IN NOCC	REDUCE TO 1 CONSOLE POSITION IN NOCC	REDUCE TO 1 CONSOLE POSITION IN NOCC	
DECENTRALIZED TROUBLE SHOOTING	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	
DECENTRALIZED SYSTEM INTEGRITY	ADDITIONAL H/W AT EACH POCC/ELEMENT (60 ASSUMED)	ADDITIONAL H/W AT EACH POCC/ELEMENT (60 ASSUMED)	ADDITIONAL H/W AT EACH POCC/ELEMENT (60 ASSUMED)	

Control Concept Refinement - Operations Management

IMPACT OF ALTERNATIVE CONTROL CONCEPT/LOAD VARIATIONS

Decentralized Troubleshooting

In this concept the isolation, identification and solution of problems would be the responsibility of the STDN elements. The impact to the NOCC would be the dispersal of the Network Support Team (NST). However, the function requires a reasonably high skill level thus dictating the presence of this skill at all STDN elements. (For purposes of casting, two members were required at five GSTDN sites and at the NASCOM control centers.)

Decentralized System Integrity

This concept retains a central control of routine service but decentralizes the system integrity. For this approach NOCC requirements are not altered but users/network elements require hardware configuration changes in terms of interactive terminals for CASMS.

Loading

The impact of loading is seen primarily in the baseline (Principal Control Concept). An increase in loading of 100% requires an increase, in accordance with the methodology for calculating network controller positions, of two controller positions. To support this increase in workload, the study team estimated an additional requirement of two scheduling positions. These personnel would be required to handle the increased number of conflicts and management 'what if'ing which will result in this environment. The relative effects resulting from varying the control concept are identical to the baseline loading. A 50% reduction will reduce the Principal Control Concepts requirements to two network controllers positions (one for TDRSS, one for GSTDN) and one scheduler position. The alternatives once again have the same relative impact except for Centralized Scheduling which now requires only one position for monitoring users' requests.

HUMAN FACTORS CONSIDERATIONS

Human Factors Considerations

ORGANIZATION OF HUMAN FACTORS INFORMATION

Five specific human factors are addressed in this report. Additionally, related information on guidelines and methodologies for human factors considerations in the working conditions of the NOCC are presented in a specialized primer found in Appendix B.

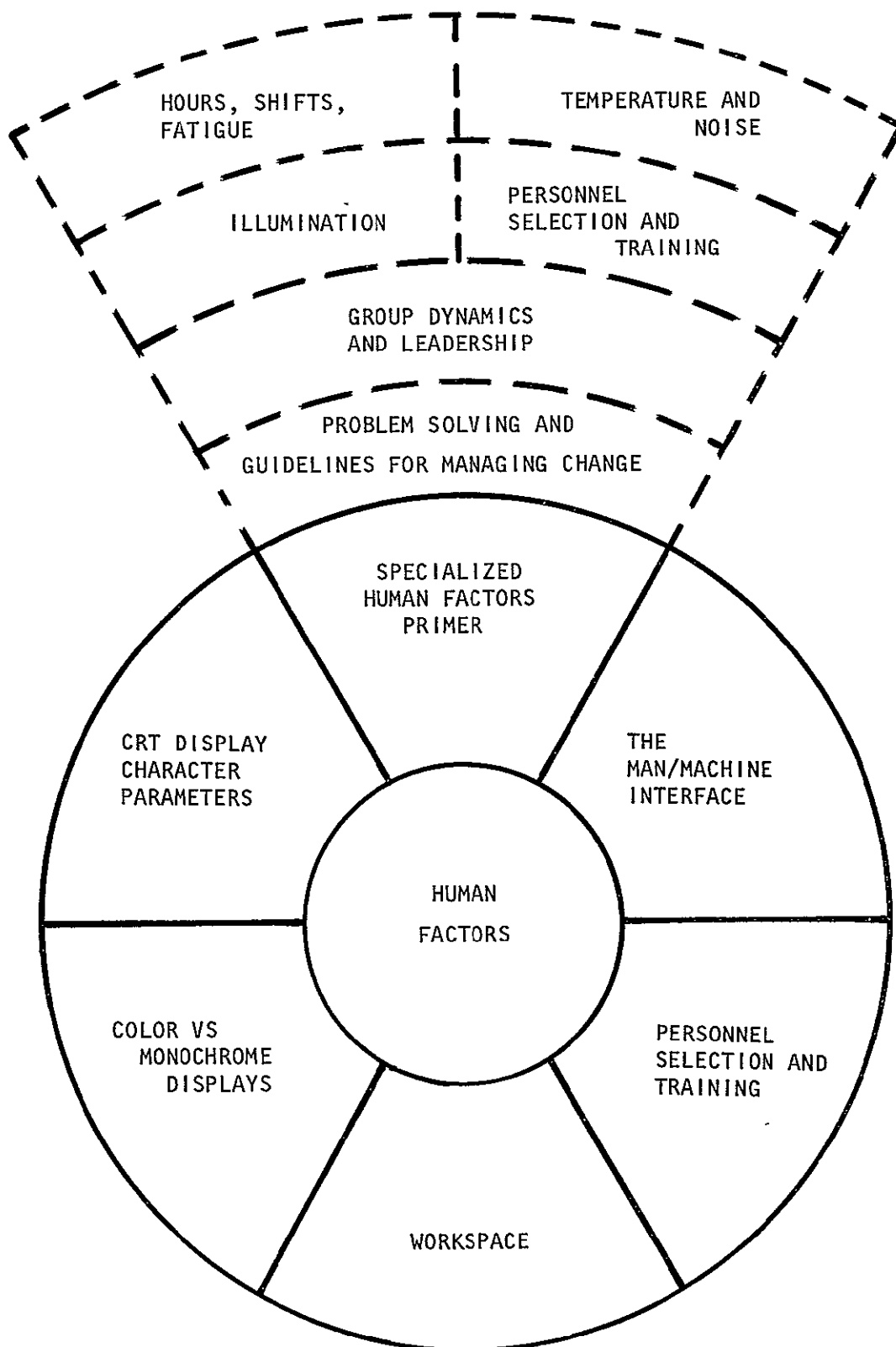
Analysis Constraints

A number of areas were identified for human factors consideration during the conduct of the Phase II analysis. Most of these areas dealt with the working conditions within the NOCC as well as the man/machine interface. The areas addressed in this report are those in which specifics could be developed at this time. Many aspects of a human factors analysis depend on detailed understanding of equipment type, building parameters, etc., which are several levels of detail below the level of analysis constrained by the objectives and resources of this study.

Organization of Material

Five specialized areas of human factors considerations are reported here the Man/Machine Interface, Personnel Selection and Training, Workspace, Color vs Monochrome Displays, and CRT Display Character Parameters. As shown in the figure, the remainder of the human factors information is provided in a primer which identifies guidelines and methodologies for related human factors considerations.

ORGANIZATION OF HUMAN FACTORS INFORMATION



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Human Factors Considerations

THE MAN/MACHINE INTERFACE

Complex man/machine interfaces are neither desired nor required within the NOCC.

Characteristics of the Man/Machine System

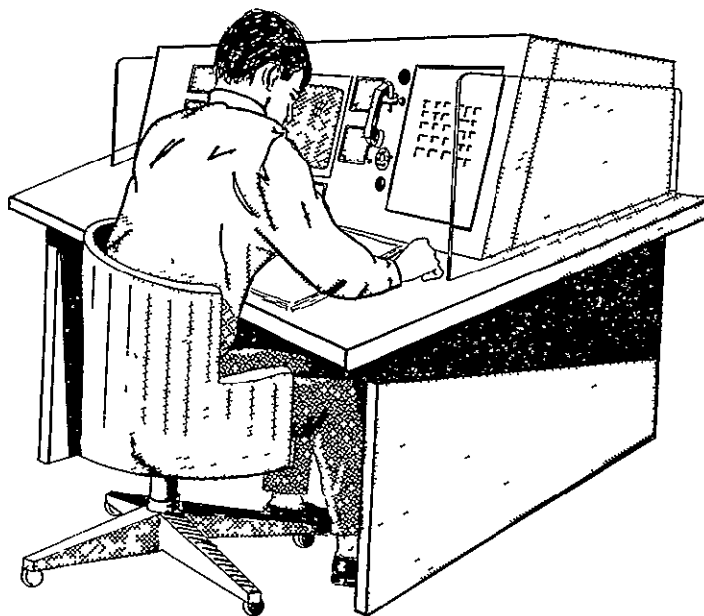
Within the STDN Operations Center, two basic types of individuals will interface with the ASR and CASMS hardware-software systems. The first type of individual spends a considerable portion of his time scanning available information looking for problems. In the operations control concept, this type includes the Network Controllers and schedulers. A shorthand term of "operators" will be used for the first type of individuals. The second type of individual is termed an analyst or spends very little time scanning. Individuals in this group concentrate on studying the properties such as amplitudes, frequencies, trends, etc. of information on their displays. These individuals include the operations control concept's Systems Analysts and Operations Manager. The responses of the "analysts" are for the most part fairly creative and not particularly predictable. The "operators" usually decide upon and implement a set of actions within certain time constraints while the analysts experiment with several alternative courses of action and may have the option of making no decision at all.

Tool Complexity-Skill Level Trade-offs

Tool complexity versus skill level trade-offs are, in the final analysis, driven by cost considerations. However, it is not the sophistication or complexity of operation of the tool that is at issue but rather the complexity of the interface between the machine and the man who must use it. Near-term investment decisions can significantly affect the complexity of the man/machine interface with a corresponding impact on skill level requirements. Therefore, the trade-offs can be viewed as a choice between near-term investment and life cycle personnel costs. Consider the following example. Day-to-day calculations performed by the NOCC computer systems are stored in memory for some period of time. If a network controller wished to access the information resulting from the calculations, there is a complex manner and there is a simple manner in which it could be displayed. A complex interface would provide the information in a "core dump" format. Thus, the individual wishing to obtain the information would be required to have detailed knowledge of core maps, the ability to work easily with number bases other than 10, and the ability to rapidly focus on specific information in a highly dense packing format. Alternatively, the simple interface would incorporate processes within the computer system to translate the machine language into a easily recognized alphanumeric format. There is an obvious difference in skill level requirement for these two interfaces. The complex interface described above would require a skill level with the characteristics previously associated with NOCC skill level 3. The simple interface could be

accomplished with a skill level of 2 as previously defined. A requirement for network controllers to possess skill level 3 capabilities would have significant impact on the life cycle personnel costs. These costs could range from an additional 100 to 200 thousand dollars per year. Personnel costs are identified in Appendix H. With a 10 year TDRSS program operational change in computer hardware-software, man/machine interface development costs would have to be in the range of 1-2 million dollars to justify not providing the simple interface for CASMS and ASR.

THE MAN/MACHINE INTERFACE



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Human Factors Considerations

PERSONNEL SELECTION AND TRAINING --- IMPORTANT CONSIDERATIONS

Formal personnel selection and training procedures could assist in the alleviation of existing NOCC working environment and morale problems.

Current Problems

During the Phase II analysis, technical interchange meetings (References 24 and 25) conducted between BDM and NASA representatives, identified specific problems related to the working environment and morale. These problems included personnel who did not effectively carry out their required tasks, tasks which related neither to the beginning or end of something, trainees shortcutting various aspects of job required skills, and variation in dress standards. Training and personnel relations can minimize these and related problems.

NOCC Personnel Selection

The tasks performed by NOCC personnel are similar to those tasks performed by radar operators and ATCs in one respect - they encompass vigilance tasks. However there is an important dissimilarity. Current or TDRSS era NOCC personnel are not expected to be required to perceive spatial differences in the information viewed, nor, are they expected to be required to view complex and interactive graphical displays. Considering these similarities and differences, some aspects existing personnel selection procedures for ATC's could prove useful to the NOCC.

A limited number of parameters have been found to be effective either as screening or predictive devices for air traffic controllers. The Civil Service Commission Air Traffic Control Specialist battery (ATCSB) has been found to be effective primarily as a screening device. The ATCSB assesses the individual's aptitude in the areas of computation, special patterns, following oral directions, abstract reasoning and letter sequences, and air traffic control problems.

The ATCSB does not attempt to measure attitudinal, motivational and other psychological factors which tend to influence performance. However, personality inventories have been found to be good screening and predictive devices in this area. Personality Scale scores (16 PF scales) have been found to have statistically significant relationships with controller performance. Smith (1974) and Buckley and Beebe (1969), References 26 and 27, for example, have tested over 11,000 air traffic controllers (combined) and characterized them as being intelligent, action-oriented and intolerant of routine. They also possessed a desire to actively participate in decision-making processes. Thackray, Reference 28, also found that extroverts, subjects scoring highest on extraversion scales, found it difficult to maintain sustained attention under monotonous, low task-load conditions.

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Smith also examined various occupational scales on the Strong Vocational Interest Test and found that none of the occupations represented in the standard inventory appear to be associated with interest patterns which clearly match the interest patterns of air traffic controllers. There was a trend in scores in the "technical supervision" area. Smith did derive an ATC scale for the Strong Inventory based on an evaluation of the occupations the controllers frequently checked as ones they liked best. These occupations were heavily weighted toward the "masculinity" dimensions: rancher, auto racer, athletic director, etc.

There is increasing evidence that the selection procedures could be improved by the addition of a variety of psychomotor performance tests such as Chiles, Jennings, and West, Cobbs and Matthews; Reference 30; Buckley and Beebe, Reference 31; and Education and Public Affairs, Reference 32; Chiles, Reference 33. The Controller Decision Evaluation (CODE) test has been found to be highly correlated with actual operator and man/machine performance. It requires the candidate to judge possible conflicts in a simplified air traffic display presented in a simulated test environment.

Recommendations

1. Administration of a modified Civil Service Air Traffic Control specialist battery to future NOCC personnel. Further attention must be given to those parts of the basic battery which relate to specific NOCC required skills and to the determination of a qualifying score.
2. Incorporation of personality assessments, through the use of the recognized 16PF scale and other measures. This procedure assures that the individual applicant's personality complements are consistent with those characteristics personnel who effectively and continuously perform certain tasks have been shown to possess.

Training

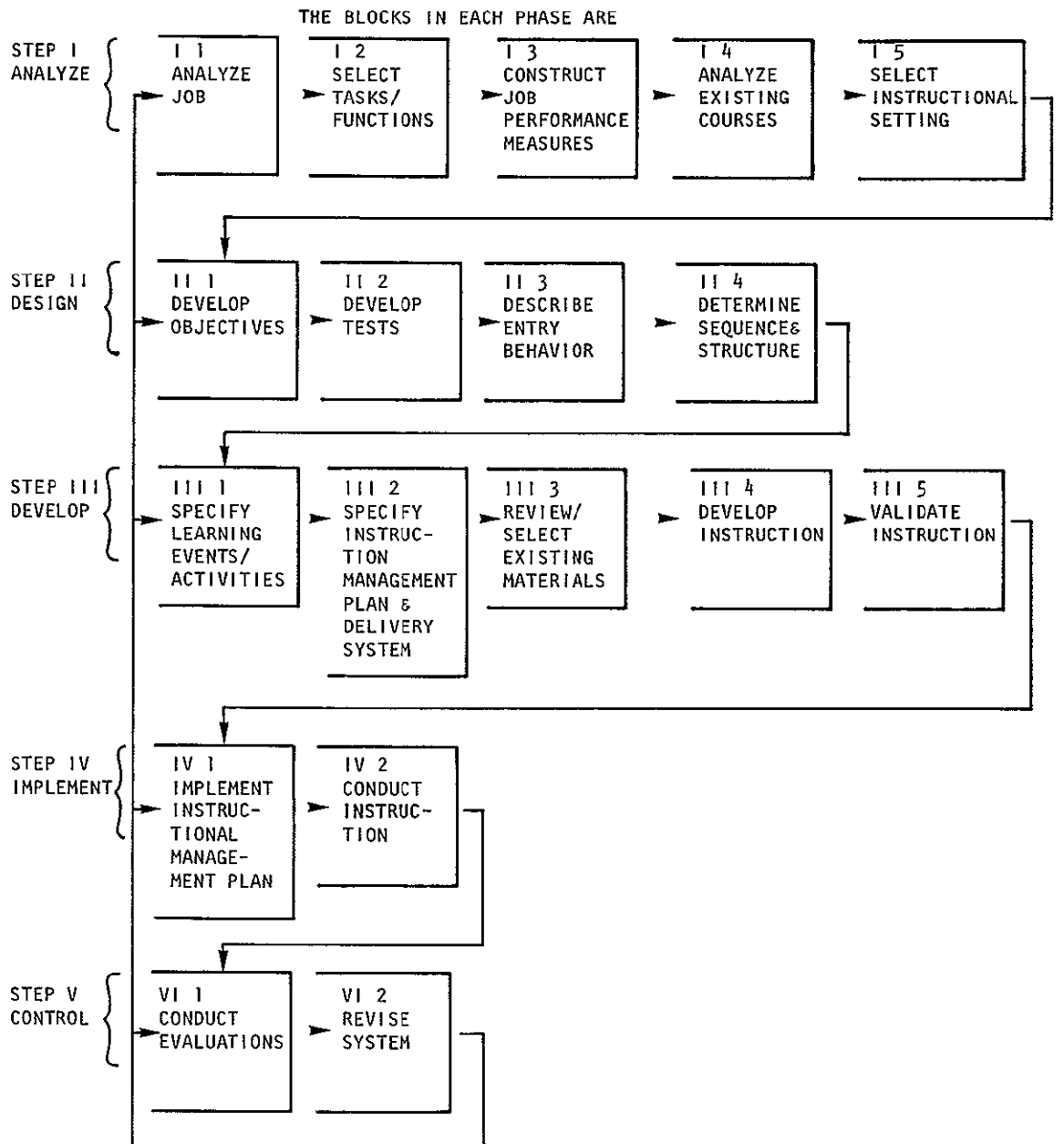
Presently, new employees are "trained" through a modified "sitting by Nellie" technique: this on-the-job type training is not mission-oriented and, because of personnel limitations, does not assure that the new employee is reinforced when his or her actions are correct or informed when actions are incorrect. This ultimately can result in the retention of inefficient and incorrect behavior.

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Human Factors Considerations

PERSONNEL SELECTION AND TRAINING --- IMPORTANT CONSIDERATIONS

PROPOSED MODEL FOR DEVELOPING NASA TRAINING PROGRAM



PROPOSED MODEL FOR DEVELOPING NASA TRAINING PROGRAM

THE PRODUCTS OF THE BLOCKS ARE

- | | |
|----------|--|
| STEP I | <ul style="list-style-type: none">1 A LIST OF TASKS PERFORMED IN A PARTICULAR JOB, OBJECTS TO BE MANIPULATED, SIGNIFICANT FEATURES OF THE ENVIRONMENT2 A LIST OF TASKS SELECTED FOR TRAINING3 A JOB PERFORMANCE MEASURE FOR EACH TASK SELECTED FOR INSTRUCTION4 AN ANALYSIS OF THE JOB ANALYSIS, TASK SELECTION, AND PERFORMANCE MEASURE CONSTRUCTION FOR ANY EXISTING INSTRUCTION TO DETERMINE IF THESE COURSES ARE USABLE IN WHOLE OR IN PART5 SELECTION OF THE INSTRUCTIONAL SETTING FOR TASK SELECTED FOR INSTRUCTION |
| STEP II | <ul style="list-style-type: none">1 A LEARNING OBJECTIVE FOR AND A LEARNING ANALYSIS OF EACH TASK SELECTED FOR INSTRUCTION2 TEST ITEMS TO MEASURE EACH LEARNING OBJECTIVE/SCHEDULE FOR DOING SO3 A TEST OF ENTRY BEHAVIORS TO SEE IF THE ORIGINAL ASSUMPTIONS WERE CORRECT4 THE SEQUENCING OF ALL DEPENDENT TASKS |
| STEP III | <ul style="list-style-type: none">1 THE CLASSIFICATION OF LEARNING OBJECTIVES BY LEARNING CATEGORY AND THE IDENTIFICATION OF APPROPRIATE LEARNING GUIDELINES2 THE MEDIA SELECTION (1) COURSE LESSON PLANS, PROGRAM OF INSTRUCTION AND TRAINING SCHEDULE 2) STUDENT HANDOUT MATERIALS 3) TRAINING MANUALS AND SIMILAR LITERATURE 4) TRAINING MEDIA AND AIDS REQUIREMENTS 5) TRAINING EQUIPMENT OR SIMULATOR REQUIREMENTS) FOR INSTRUCTIONAL DEVELOPMENT AND THE INSTRUCTIONAL MANAGEMENT PLAN FOR (1) TESTING MATERIALS AND PROCEDURES FOR MONITORING THE QUALITY OF TRAINING 2) TESTING MATERIALS AND PROCEDURES FOR DIAGNOSIS OF INSTRUCTIONAL DIFFICULTIES AND INSTANCES OF TRAINING INEFFECTIVENESS) FOR CONDUCTING THE INSTRUCTION3 THE ANALYSIS OF PACKAGES OF ANY EXISTING INSTRUCTION THAT MEETS THE GIVEN LEARNING OBJECTIVES4 THE DEVELOPMENT OF INSTRUCTION FOR ALL LEARNING OBJECTIVES WHERE EXISTING MATERIALS ARE NOT AVAILABLE5 FIELD TESTED AND REVISED INSTRUCTIONAL MATERIALS |
| STEP IV | <ul style="list-style-type: none">1 DOCUMENTS CONTAINING INFORMATION ON TIME, SPACE, STUDENT AND INSTRUCTIONAL RESOURCES, AND STAFF TRAINED TO CONDUCT THE INSTRUCTION2 A COMPLETED CYCLE OF INSTRUCTION WITH INFORMATION NEEDED TO IMPROVE IT FOR THE SUCCEEDING CYCLE |
| STEP V | <ul style="list-style-type: none">1 DATA ON INSTRUCTIONAL EFFECTIVENESS2 DATA ON JOB PERFORMANCE IN THE FIELD3 INSTRUCTIONAL SYSTEM REVISED ON BASIS OF EMPIRICAL DATA |

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Human Factors Considerations

PERSONNEL SELECTION AND TRAINING --- IMPORTANT CONSIDERATIONS

Program Development

The methodology shown in the figure for the development of a NOCC training program is a synthesis of proven methodologies for numerous training programs. References are provided in the Human Factors bibliography associated with Appendix G. The methodology has a central theme: training must be responsive to the requirements of the job.

Training experts have emphasized the importance of Step 1 in the methodology shown in the figure - analysis of the job itself. The following discussion of what is involved in this step serves to demonstrate why it would be presumptuous of BDM to specify a training program at this time.

In Step 1, an inventory of job tasks is compiled and divided into two groups: tasks not selected for instruction and tasks selected for instruction based upon task criticality. Those tasks identified as requirements for the training program would be described in detail. The description would provide identification of each step required for performance of the task in terms of the action to be taken, the object to be manipulated, and the means for determining the step was performed correctly. Also included would be identification of significant features of the work environment associated with task performance. Job performance standards for tasks selected for instruction are determined by interviews or observations at the job site and verified by experts. Entry level performance standards are derived from these observations. The analysis of existing course documentation is done to determine if all or portions of the analysis phase and other phases have already been done by someone else. As a final analysis step, the list of tasks selected for instruction is analyzed for the most suitable instructional setting for each task. The selection process would involve evaluation of the tasks against the following criteria: (1) Task criticality, (2) Task similarity to other tasks in the inventory, (3) Resource requirements and availability for the means considered, (4) Relative time required to attain proficiency, (5) Time available to develop proficiency, (6) Number of personnel to be trained, (7) Whether a prerequisite ability for task performance already exists in trainee population.

The essential products of the other steps are shown in the figure.

Recommendation

Implementing a training program may increase NASA organizational efficiency through the attainment of necessary skills and employee behavior. Consideration should be given to detailed analyses of the tasks that are presently being performed by NOCC and support employees in the course of program design

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Human Factors Considerations

MINIMAL WORKSPACE ESTIMATED FOR NOCC POSITIONS

A minimal working space of 192 square feet for console positions and 90 square feet for desk, or office positions was established.

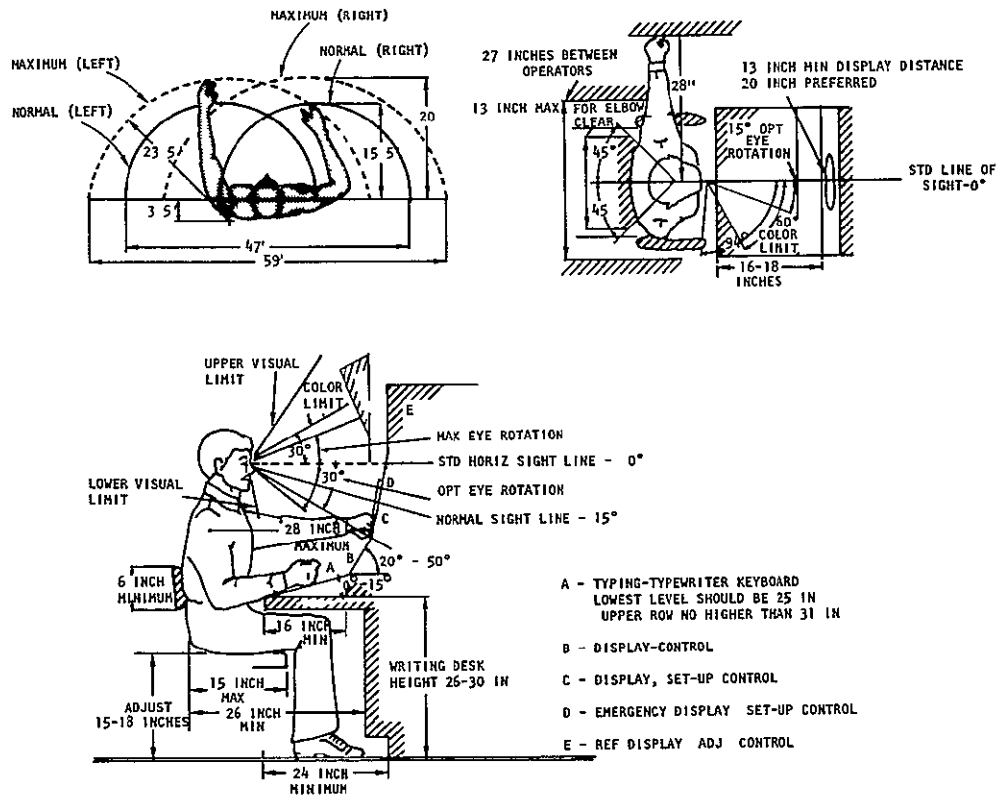
INTRODUCTION

As the STDN evolves into its TDRSS era configuration, the operations center configuration is most likely to change. This change could be motivated to a large extent by equipment changes and staffing requirements and other related factors (such as economic). To aid in the establishment of new building space requirements or requirements for additional space in the existing operations center, area minimal workspaces were established for console positions and office areas. These workspace figures are subsequently utilized as part of the data in the cost analysis presented in the next section and Appendix H. A heuristic approach was applied to the determination of the workspace dimensions. Anthropometric studies provided guidelines for minimum and maximum dimensions for seated and console type configurations. These are summarized in the figure. Additionally, basic references in human engineering (e.g. Reference 21 and 36) provided the guidelines for "guard" space and aisles.

Console Positions

As can be seen in the figure, the overall reach of an individual is limited to approximately 60 inches. The depth of the current NOCC consoles was estimated to be approximately 40 inches. Discussions with operations personnel as well as personal observations indicated that both writing and storage room is currently very limited at console portions. The console position workspace identified in the figure provides a storage and writing space of six feet in length and two and one-half feet in depth. There are nominal dimensions which could be configured as a bookcase and small table, small file cabinet and table, etc. It should be noted that the recommended minimal writing area for typical writing tasks is 24 inches in length and 16 inches in depth (Reference 36). Because of other considerations, such as open procedure notebooks, operational checklists, coffee cups, reference papers, etc; additional room was incorporated in the storage and writing space area shown. The "guard" space around the working area is approximately 36 inches. This space is the recommended dimensions for one person passing another against the wall. Observations of traffic patterns within the NOCC was the basis for this recommendation. When two work areas are placed next to each other, the guard space provides adequate room for two people to pass in the aisle formed by the guard space. If two console positions are placed side by side, the "guard" space between consoles is ignored. However, the combined console workspace should include another equivalent storage and writing area and guard space around the periphery.

WORKPLACE DIMENSIONS AND GENERAL LAYOUT



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Human Factors Considerations

MINIMAL WORKSPACE ESTIMATED FOR NOCC POSITIONS

This guard space is an important consideration in the NOCC where transient personnel, such as those with messages in performing support, liaison or resisting, could hamper operations.

Finally, movement space is provided between the console itself and the storage and writing area. This dimension is based on the guidelines provided in Reference 36 .

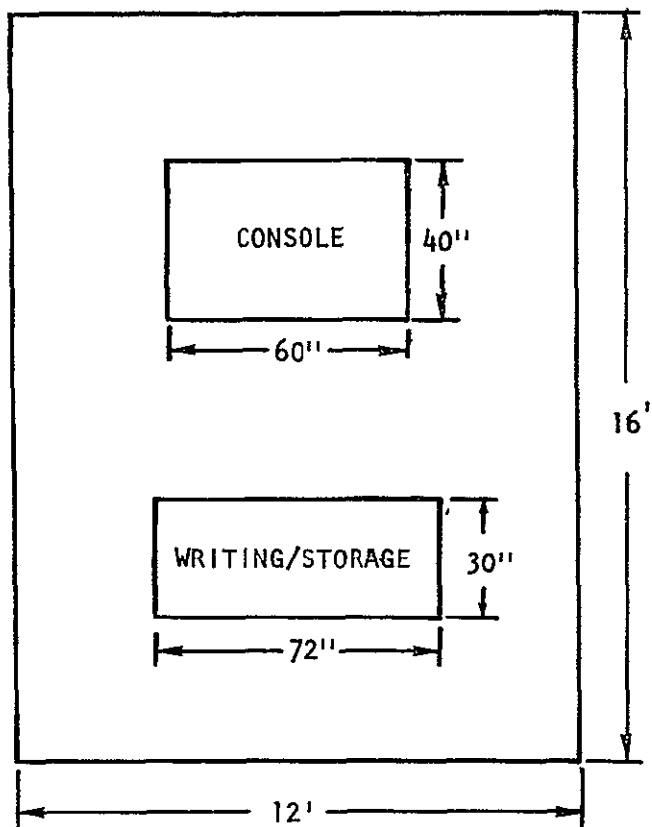
Office Positions

The NOCC operations personnel will be supported by various individuals who do not require direct access continuously to the operations area. Work space considerations for these individuals are somewhat different. Standard assumptions have been made concerning a requirement for a desk work table and bookcase. Observations of the amount and packaging of material usually found in offices in the Network Operations Division suggested the need for two bookcases. This furniture was assumed to have the standard sizes. The arrangement shown is obviously not critical to the space allocation specification.

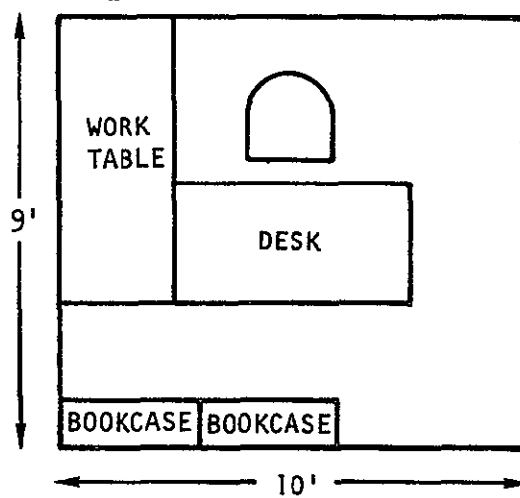
Room around the desks and bookcases provide for traffic in these areas. When two office type work spaces are joined, relevant factors concerning aisles must be considered as described above.

WORKSPACE ESTIMATES

OPERATIONS
WORKSPACE



SUPPORT
WORKSPACE



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Human Factors Considerations

NO DEFINABLE REQUIREMENT FOR NOCC COLOR CRT DISPLAYS

The information displayed on NOCC CRTs, and available monochrome information enhancement techniques obviate the requirement for color CRT displays in the NOCC.

Considerations

As in the current NOCC, the cathode ray tube (CRT) display will provide the machine interface point with man in the TDRSS era control center. Consideration was given to the possibility of using color CRT displays to enhance this man/machine interface. The results of Rouse (Reference 34), and an FAA color display evaluation study (Reference 35) formed the foundation of the information reviewed during this aspect of the analysis. It should be noted that very little actual data has been collected in the human factors community on the tradeoff between color and monochrome CRT displays. Most studies in the past have experimented with pigments, films, lights, static and never-to-be operational materials (Reference 35).

However, the displays considered for the NOCC, as previously described, and the similarity between FAA ATCs and NOCC personnel in vigilance type tasks allow some conclusions to be drawn from the data available.

Color Displays

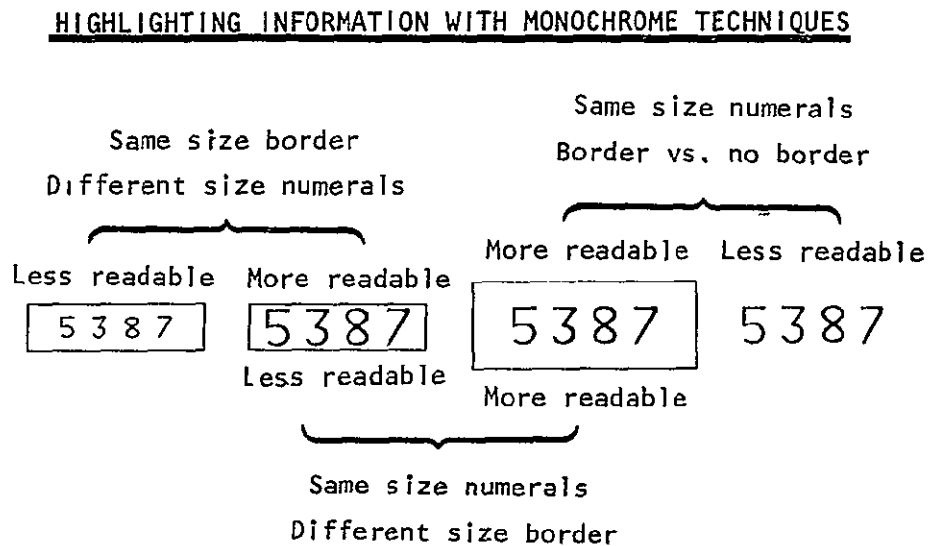
The use of color lends itself more effectively to situations which can be graphically portrayed or where one item such as a character or word must be quickly and accurately distinguished from other items. Color is also suited for identifying important information where such data is presented in the form of overlapping characters. Color displays may be beneficial in reducing boredom and fatigue. The FAA study reported that most air traffic controllers reported feeling that color helped them do a more effective job. However, the actual measured performance did not identify any significant difference in job performance. In the same study it is also stated that "there were hints that color coding applications tested might increase the judgmental accuracy of some controller" (Reference 34).

The costs for color displays can modestly be estimated to be 25% greater than for a comparable monochrome CRT display. The technology involved in color CRT production also reduces the resolution available on color displays.

Monochrome

The physics of monochrome displays is well understood with production repeatable technology currently established. Most of the applications for

color such as attracting attention to important information, highlighting sets of information, etc., can be accomplished with monochrome techniques. Some of those techniques have been suggested previously in the presentation of the CASMS displays (page III-52). In these display examples important information was boxed or "blinked". These two techniques significantly aid in drawing an observers attention to control information. Guidelines state (Reference 21) that within a given limited space, the figures should be as large as possible. For a given size of figure, a larger surrounding border contributes to readability. Some of these relationships are shown in the figure.



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Human Factors Considerations

RECOMMENDED CRT CHARACTER PARAMETERS

For the CRT displays in the STDN Operations Center, alphanumeric characters should be 0.30 to 0.37 inches in height.

Derivation of Character Size

In many cases character size and legibility are governed by aesthetic rather than technical considerations. However, when one considers the CRT display, there are definite limits on the size of the character formed by a group of illuminated phosphor dots. The upper limit is shown on the graph--the solid line designating a resolution viewing factor of 6. The lower bound, indicated by the second solid line designated as resolution viewing factor of 2, shows the lower limit for character legibility.

The "resolution viewing factor" (F) is the ratio of the size of one element (dot) in the standard 5 x 7 dot matrix to the size of the smallest element resolvable to the eye. This 5 x 7 matrix is the one used in most available CRT's. Such an element subtends an arc of approximately one minute.

The formula for converting the resolution viewing factor into an actual linear measurement is

$$h = R\theta$$

Where h = The alphanumeric character height
 R = The normal distance from viewer to screen
 θ = The angle (in radians) subtended by the height of the character,

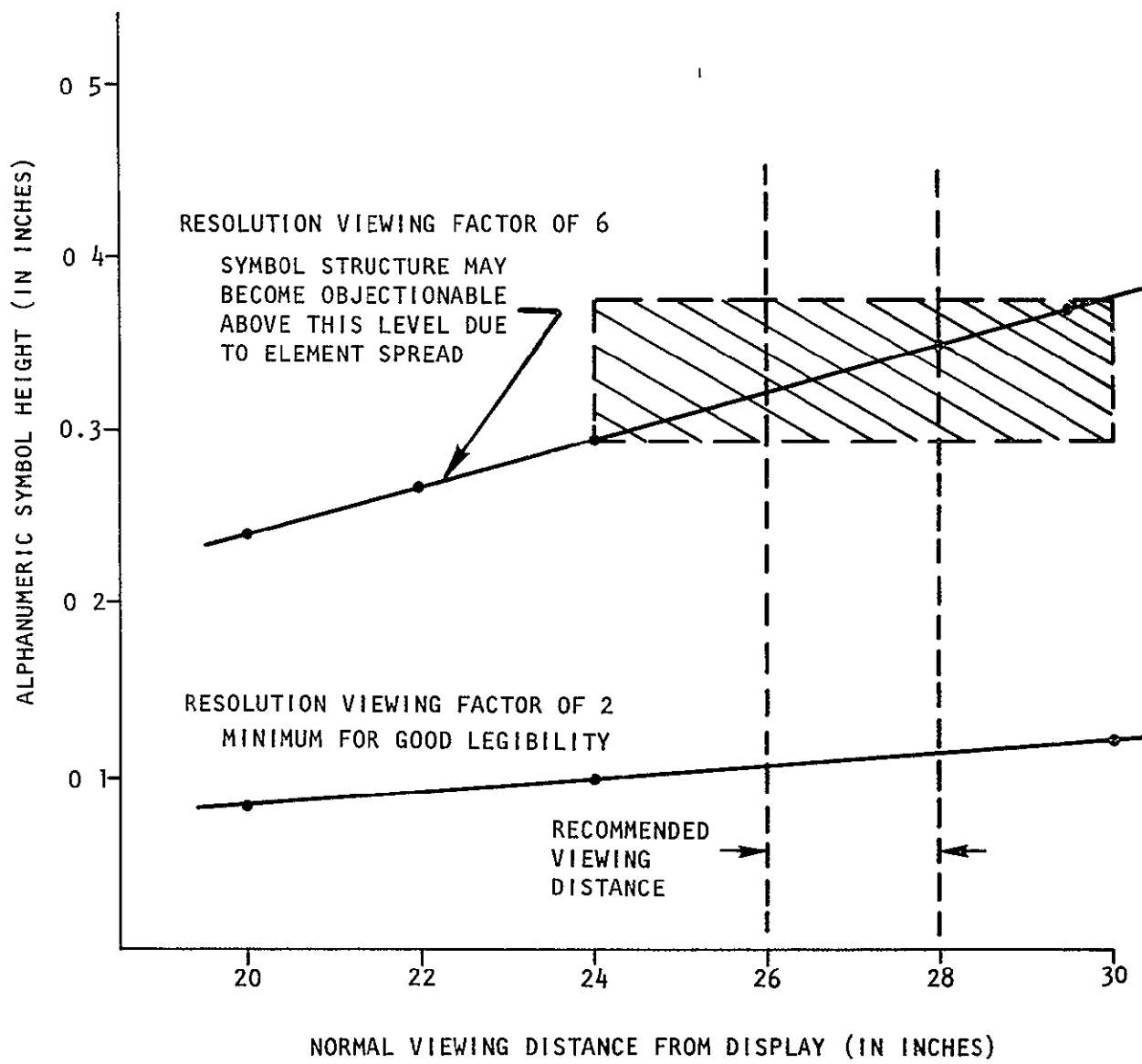
Thus $\theta = (7 \times F) \text{ minutes of arc} \times 1/60 \text{ degrees per min of arc} \times \pi/180$
 radians per degree
 = $7\pi F/10800$ radians.

Maximum and minimum alphanumeric symbol heights are shown for viewing distances of 20-30 inches.

Recommendations

Nominal viewing distances in the NOCC are expected to fall in the range of 24-30 inches. The points on the F=6 line form the basis for the shaded areas identified in the figure

RECOMMENDED CRT ALPHANUMERIC SYMBOL HEIGHT



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COST ANALYSIS

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Cost Analysis

STANDARD COST ANALYSES USED

Life Cycle Costing (LCC) provides the methodology by which system program costs can be evaluated; discounting is the mechanism by which alternative systems programmed funding flows can be evaluated.

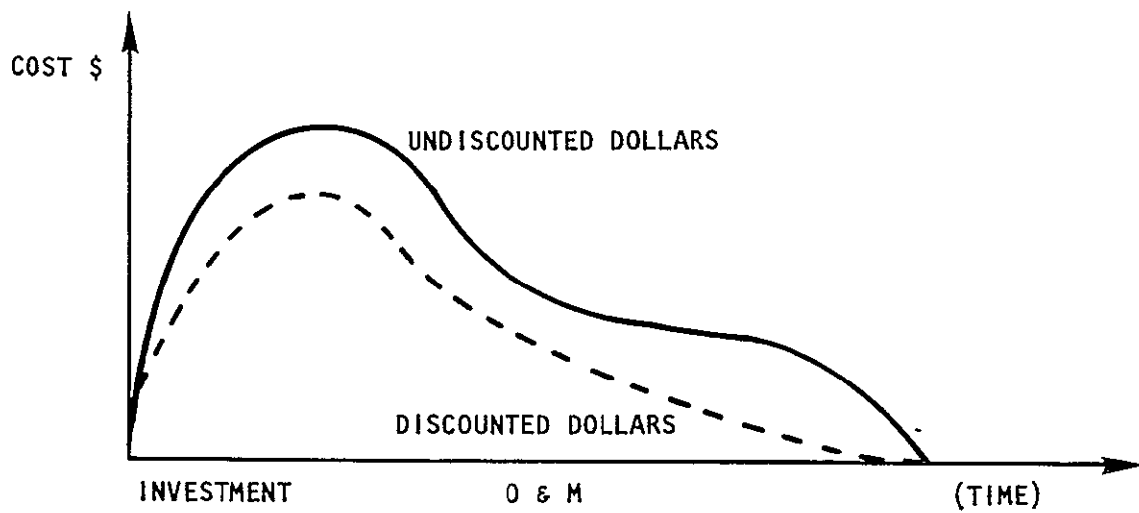
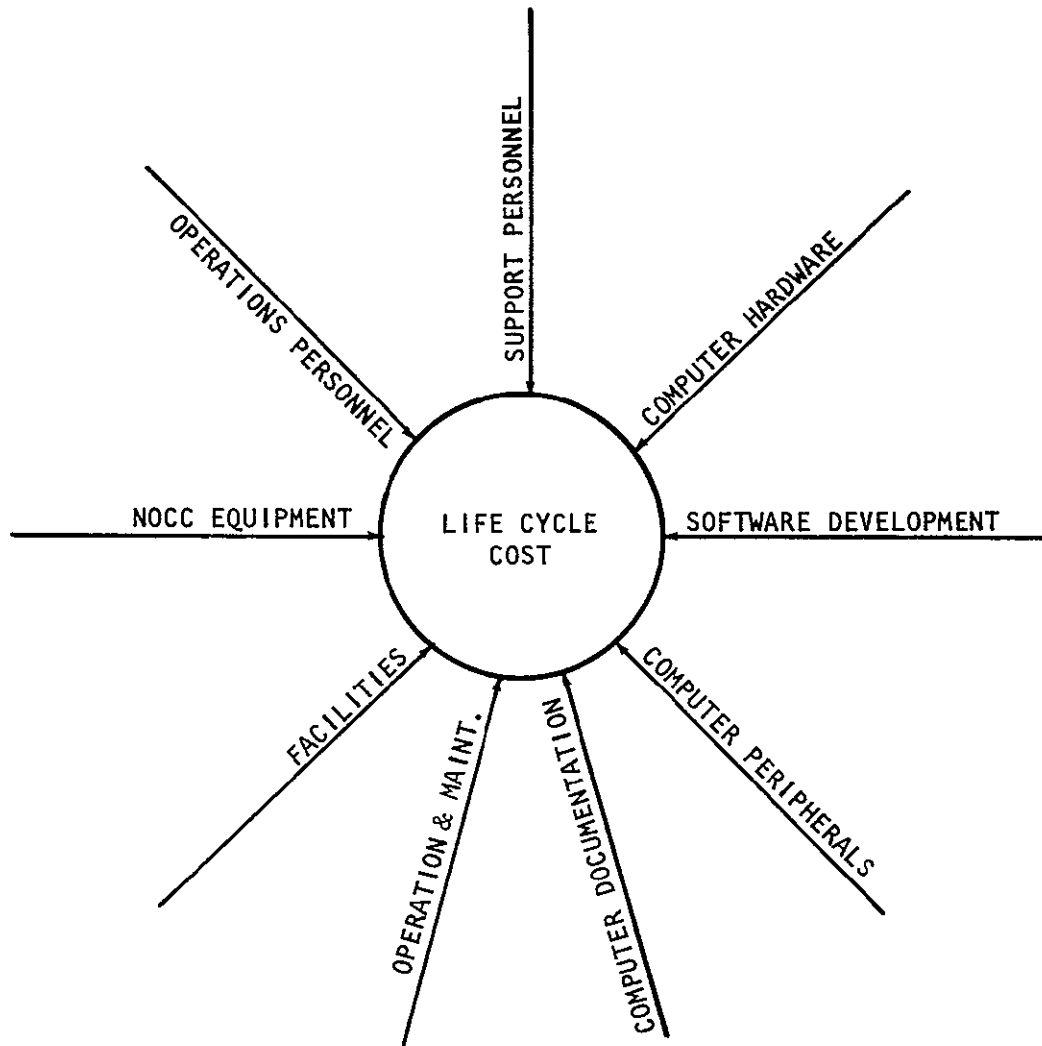
LCC Methodology

Life Cycle Costing provides the methodology by which total costs, from system preliminary design and development to retirement, are broken out by a chronological accounting system which tracks RDT&E, investment and operation and maintenance expenditures. The figure illustrates the cost components addressed in the Operations Control Concept life cycle costing analysis. In the area of Research and Development, the cost of developing the two computer system software packages (CASMS and ASR) have been estimated, based on BDM expertise in this field. Computer investment costs were based on system requirements and reflect manufacturer estimates of designated hardware configurations. Facility costs were derived from cost estimating relationships (CERs) previously formulated by BDM for related costing studies. NOCC equipment costs were calculated, based on manufacturers costs of CRTs and estimates of console configuration, computer peripheral requirements, and miscellaneous requirements such as storage space for documentation, tables, chairs, and bookcases. Operation and Maintenance (O&M) costs of the system are primarily dependent on personnel requirements. The skill and number of required personnel for operations and support have been derived. Costs for personnel were estimated, given the skill requirement from the current government General Schedule (GS). Also accounted for is O&M on the computer hardware.

Discounting

In analyzing LCC, the time value of money is critical for understanding and correctly employing cost information for decision making. Most decision makers are aware of the negative effect of inflation in reducing the purchasing power of programmed funds and resulting in increased cash outlays and time. However, there is a second effect accounting for the positive time performance of money. The figure depicts the effect of discounting; future dollars are more important than current dollars. By discounting inflated dollars, the present value of future cash flows can be compared on a common basis, accounting for both positive and negative effects of time. In addition, discounting ensures government efficiency in resource allocation by comparing cash flows discounted at a rate competitive to the rate of return in private investment. This is an important criterion since government funds are, for the most part, currencies displaced from private consumers and businesses. Therefore, the return to government expenditure must be compatible to ensure efficiency in resource allocation. Discounted costs were used as the means of control concept alternative comparisons in the cost analysis

LIFE CYCLE COSTING AND THE EFFECT OF DISCOUNTING



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Cost Analysis

PRINCIPAL CONTROL CONCEPT COST

The cost of the Principal Control Concept in 1976 dollars is approximately eleven and a half million dollars.

Development Costs

Software development of the two computer systems, ASR and CASMS, was derived, based on preliminary specifications developed during the Phase II Analysis. Both systems were estimated to cost between 250-400 thousand dollars, with CASMS closer to the lower limit and ASR approaching the upper. As the LCC table indicates, a conservative estimate for software development of both systems was 800 thousand dollars.

Investment Costs

Facility requirements were estimated at approximately 20 thousand square feet including the NOCC and support areas. Estimates were based on refurbishment of present facilities at a cost of approximately 250 thousand dollars. Cost of a new building was estimated from one to one and a half million dollars.

Computer hardware costs were calculated from preliminary system requirements generated by the study team and included cost of the central processors, peripherals, and terminals. Costs were based on manufacturer's retail prices. Cost of ASR hardware was estimated to be approximately 200 thousand while CASMS was estimated to be 80 thousand dollars.

NOCC equipment was estimated to range from approximately 90 to 135 thousand dollars and included CRTs, console structures, printers, and miscellaneous furniture.

Operations and Maintenance Costs

Personnel costs comprised the largest portion of the program cost and reflect the relative skill levels and position requirements of the NOCC functions. Estimates for given skill levels were derived from the governments General Schedule (GS). The cost represents the means of the low-high range for the total personnel requirements. The total estimated personnel cost was approximately 900 thousand dollars a year.

The O&M on the computer hardware was estimated to be approximately ten percent a year of the total hardware investment cost or approximately 28 thousand dollars.

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Inflation and Discount Rates

For purposes of analysis, a 6% inflation rate was assumed. 6% represents an estimated average rate for the fourteen year period under consideration and does not vary significantly with recent quarterly estimates of price changes. As previously discussed, the social rate of discount reflects the opportunity cost of sacrificing current consumption for future consumption. However, there is no one agreed upon discount rate which reflects the appropriate rate of public project evaluation. Rates recommended by economists range from 4% to 14%, although the more current estimates are from 8% to 14%. For purposes of this study, a 10% rate of discount was assumed. This is the rate used in the economic analysis of the Space Shuttle.

Total Costs

The total life cycle cost of the Principal Control Concept was estimated to be approximately eleven and a half million dollars in 1976 dollars, nineteen million in inflated dollars, and eight and a half million in discounted dollars.

PRINCIPAL CONTROL CONCEPT • LIFE CYCLE COSTING																			
	FY	77	78	79	80	81	82	83	84	85	86	87	88	89	90	T	IT	OT	
FACILITY			125	125												25			
INFLATED (6%)			14	15													29		
DISCOUNTED (10%)			12	11														23	
HARDWARE			28													28			
INFLATED			31														31		
DISCOUNTED			26															26	
SOFTWARE DEV		4	4													8			
INFLATED		424	449														873		
DISCOUNTED		385	371															756	
NOCC EQUIPMENT		1														1			
INFLATED		11															11		
DISCOUNTED		09																09	
PERSONNEL																			
INFLATED					1 14	1 2	1 28	1 35	1 43	1 52	1 61	1 7	1 8	1 9	2 03	9 9	16 96		
DISCOUNTED					77	76	72	69	67	64	62	59	57	55	53			7 11	
O & M					028	028	028	028	028	028	028	028	028	028	028	308			
INFLATED					035	037	04	042	044	047	05	053	056	059	063		526		
DISCOUNTED					024	023	023	022	021	02	019	019	018	017	017			223	
																11 64 19 0	8 7		

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Cost Analysis

DECENTRALIZED ROUTINE SERVICE COST COMPETITIVE

The most desirable alternative from the standpoint of cost is the Decentralized Routine Service.

Impact on Baseline Composition

For the alternative control concepts developed in Phase I, Life Cycle Costing estimates were derived using the Principal Control Concept as the bases for comparison. As the figure illustrates, for a given mission loading, changes in the control philosophy will alter the composition of the baseline Principal Control Concept. The following is a synthesis of the effects on network resources as derivations of the Principal Control Concept are presented.

Centralizing the control of scheduling results in the addition of one to two scheduling positions in the NOCC. Network controller positions are reduced by Decentralizing Routine Service, however, the hardware configurations of the users are affected since decentralized access to CASMS is now required. This hardware cost is also relevant to the Decentralized System Integrity Concept but in this case personnel requirements are not altered. The most drastic requirement results from Decentralized Troubleshooting since the Technical Support Group (TSG), germane to the Principle Control Concept, is dispersed and replaced by on-site personnel responsible for the identification, isolation, and resolution of STDN network problems. The effect on cost for each of the cycle costing information

The cost of the alternatives are presented in 1976 dollars, inflated dollars, and discounted dollars. Also provided is the percentage change from the discounted baseline (Principal Control Concept) costs. As seen in the "%Δ" column, only one alternative, Decentralized Troubleshooting, varied from the baseline by more than 10%. Here the change resulted in a 18% increase in discounted dollars and a 20% in inflated programming expenditures (not displayed in the table). Decentralized Routine Service results in a cost decrease to the STDN system, however, personnel costs to the POCCs were not calculated. The effect of Centralized Scheduling is seen in the 9% increase in discounted costs and a 10% increase in inflated costs.

The range for all alternatives given the TDRSS Baseline Mission Model is 17.6M - 22.85M in inflated dollars. From purely the standpoint of cost, assuming each alternative equally services the system, the most attractive choice is the Decentralized Routine Service.

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Impact of Mission Loading

The absolute impact of a one hundred percent increase in loading is to increase the inflated baseline Principal Control Concept costs by 25%. This is a result of the increased position requirements for controllers and schedulers. In the relative sense, the alternatives have not changed desirability (rank) in terms of cost. However, the Decentralized Routine Service compares even more favorably with the Principal Control Concept than it did in the Baseline Mission Model Case.

With a fifty percent reduction in the loading the Principal Control Concept becomes as attractive an alternative as the Decentralized Routine Service. Again, the comparisons are made solely on the basis of cost, and in addition, PCCC personnel costs were treated as variables. Note that the Decentralized Trouble Shooting Concept remains the most costly for all loading levels.

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CONTROL CONCEPT	CHANGES IMPACTING COST			BASELINE MISSION MODEL (\$M)				100% INCREASE IN BASELINE (\$M)				50% REDUCTION IN BASELINE (\$M)				COMMENTS
	BASELINE MISSION	100% INCREASE	50% REDUCTION	76	INF	DIS	% Δ	76	INF	DIS	% Δ	76	INF	DIS	%	
PRINCIPAL	3 CONTROLLER POSITIONS 2 SCHEDULER POSITIONS	2 ADDITIONAL NC AND SCHED POSITIONS	2 CONTROLLER POSITIONS 1 SCHEDULER POSITION	11 64	19 0	8 7	-	14 39	23 83	10 67	-	10 76	17 6	8 07		CONFLICT RESOLUTION DECENTRALIZED, ADDITIONAL FUNCTIONS MUST BE ABSORBED BY ELEMENTS/USERS
CENTRALIZED SCHEDULING	1-2 INCREASE IN SCHEDULING POSITION REQUIREMENT	1-2 INCREASE IN SCHEDULING POSITIONS OVER BASELINE REQ	INCREASE OF 1 SCHEDULING POSITION	12 74	21 01	9 5	9 1 %	15 27	25 35	11 31	6%	11 2	18 4	8 36	3 5%	
DECENTRALIZED SCHEDULING	NONE	NONE	NONE	11 64	19 0	8 7	-	14 39	23 83	10 67	-	10 76	17 6	8 07	-	
MATRIX SCHEDULING (CENTRALIZED MAINTEN- ANCE SCHEDULING)	1 EXTRA SCHEDULER 1 SHIFT	1 EXTRA SCHEDULER 1 SHIFT	1 EXTRA SCHEDULER 1 SHIFT	11 75	19 3	8 78	09%	14 5	24 0	10 75	.07%	10 75	17 6	8 00	0 0%	
MATRIX SCHEDULING (CENT MAIN/NON- GSFC POCC SCHEDULING)	1 EXTRA SCHEDULING POSITION	1 EXTRA SCHEDULING POSITION	1 EXTRA SCHEDULING POSITION	12 3	20 34	9 16	5 2 %	14 94	24 77	11 06	3 7%	11 2	18 4	8 36	3 5%	SET UP IS CENTRALIZED AND IS MAJOR PART OF WORKLOAD
CENTRALIZED ROUTINE SERVICE	NONE	NONE	NONE	11 64	19 0	8 7	-	14 39	23 83	10 67	-	10 76	17 6	8 07	-	
DECENTRALIZED ROUTINE SERVICE	REDUCE TO 1 CONTROLLER POSITION IN NOCC H/W-\$100/MO PER USER (50)	REDUCE TO 1 CONTROLLER POSITION IN NOCC H/W-\$100/MO PER USER (50)	REDUCE TO 1 CONTROLLER POSITION IN NOCC H/W-\$100/MO PER USER (50)	10 75	17 6	8 05	-7 4 %	12 32	20 2	9 14	-14 3%	10 75	17 6	8 05	- 2%	
DECENTRALIZED TROUBLE SHOOTING	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	TSG DISPERSED 1-2 PERSONNEL AT ALL STDN ELEMENTS (6 ASSUMED)	13 84	22.85	10.26	18 %	16 04	26 7	12 72	19 2%	12 29	20 23	9 2	14 0%	
DECENTRALIZED SYSTEM INTEGRITY	H/W-\$100/MO PER POCC/ELEMENT (60 ASSUMED)	H/W-\$100/MO PER POCC/ELEMENT (60 ASSUMED)	H/W-\$100/MO PER POCC/ELEMENT (60 ASSUMED)	12 43	20 43	9 2	5 7 %	15 18	25 21	11 24	5 3%	11 55	18 97	8 7	7 8%	TO ACCESS EITHER CASMS OR ASR, NETWORK CAPABLE PEOPLE IN POCC/USER

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APPENDICES

APPENDIX A
DESCRIPTION OF QUANTITATIVE ANALYSIS TOOLS

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APPENDIX A
DESCRIPTION OF QUANTITATIVE ANALYSIS TOOLS

A. INTRODUCTION

This appendix describes the quantitative analysis tools utilized to support the Phase I TDRSS Operations Control Analysis Study. Specifically these tools were:

- (1) The Mission Loading Model
- (2) Conflict Analyzer
- (3) Zero-Order Conflict Resolver
- (4) System Queuing Model.

To maintain a high degree of flexibility, each of these computerized tools is data driven to the maximum extent. Throughout this appendix, reference is made to specific numerical values utilized as input data to these models. It should be kept in mind that these values are not necessarily "hard wired" attributes of the computer code. The following sections of this appendix describe the attributes and functions of each of these computerized tools.

B. MISSION LOADING MODEL

A computer program was developed that calculated the daily loading on the TDRSS for each satellite contained in the TDRSS Mission Model (Reference 1). The program was used to display the daily load on the forward and return links of both the single access (SA) and multiple access (MA) service provided by TDRSS. Using this program, estimates of system free time were made as well as percentage increases and decreases in loading. Additionally, the impact on these figures caused by varied durations of tracking was analyzed.

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1. Inputs

Inputs to the program were

- (1) A two-letter satellite design code
- (2) An identifier (MA=1, SA=2)
- (3) A class (special programming provision for return link only or forward link only)
- (4) Number of satellites of the given design
- (5) Time per contact (minutes)
- (6) R/F ratio (return link-to-forward link ratio)
- (7) Number of contacts per orbit
- (8) Orbital height (not shown on the computer printout)

An assumption of one-minute duration on the forward link per contact was made for every satellite except EE, which was assumed to have high command activity for orbital maneuvers and thus had a forward link contact of three minutes.

2. Outputs

The outputs were the total loading in minutes on the forward and return links on MA and SA. The "total" column for each mission closely corresponds to the "Minimum Support Requested" column of the July 1975 Mission Model used in the analysis. As an example, (see Figure A-4) HEA0 (designated as HE) has a requirement for 11.8 hrs/day of coverage on MA.

$$\begin{array}{r} 11.8 \text{ Hrs} \\ \times 60 \\ \hline 708 \text{ Minutes} \end{array}$$

It also has the requirement to be tracked once per orbit. Its proposed orbital height is 370 km which translates to approximately 16 orbits per day. HEA0 was assigned two 22-minute passes per orbit, one with tracking and data and one with data only.

$$\begin{array}{r} 22 \text{ minutes/orbit} \\ \times 16 \text{ orbits/day} \\ \hline 352 \text{ minutes/day} \\ \times 2 \\ \hline 704 \text{ minutes/day total service.} \end{array}$$

This closely matches the 708 minutes/day requirement.

3. Loading Variations

The effects on the Principal Control Concept were to be studied at loads of +50% of baseline as well as at baseline itself. The load variations were to be evenly distributed among all mission classes.

To accomplish this, an appropriate number of minutes was added to or subtracted from all four links to observe the required totals of +50% of baseline. To insure that whole satellites with realistic support requirements were added or subtracted, fractions of satellite groups having similar service characteristics were changed. Multiple missions of the same type were then added or subtracted. Next, arbitrary choices were made to balance the load, and, finally, an auxiliary satellite labeled "spare" (SP), was created with realistic support requirements that made up for any difference remaining between the true figures and the calculated figures.

The following is a list of how all loads from -75% to +100% were derived:

(1) Start with Baseline Load

(2) For +25% ADD

1 NASA/INT

1 EXT X-RAY

1 AEM (but track only once per orbit using MA and none using SA)

1/2 HEAO (i.e. 10 minutes data on MA once per orbit;
1 minute track once per orbit)

1 EOS/ERS

SPARE = 7 minutes data on MA once per orbit

6 minutes data on SA once per orbit

one track per orbit on SA

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- (3) For +50% ADD
2 NASA/INT
1 EXT X-RAY
1 ENV MON
1 EOS/ERS
2 AEM
1 HEAO (with only one 21 minute data contact per orbit
and one 1 minute track per orbit)
SPARE = 6 minutes data on MA twice per orbit
10 minutes data on SA twice per orbit
track on SA twice per orbit for 1 minute each
- (4) For +75% ADD
All of +50% plus:
1 GRV PRB
1 BESS
1 COSM BKD
1 SEASAT-B
1 TIROS
1 EXT X-RAY
1 SPARE = 4 minutes data on MA once per orbit
9 minutes data on SA once per orbit
track once per orbit on SA
- (5) For +100%, double the number of satellites in every category
- (6) For -50%, start with Baseline and subtract:
2 NASA/INT
GRAV PRB
BESS
COSM BKD
EXT X-RAY
2 ENV MON
AEM
2 EOS/ERS

Use HEAO with 18 minute data MA contact twice per orbit and one track per orbit

SPARE = one contact per orbit SA for 15 minutes with 10 minutes data and 5 minutes tracking

- (7) For 25%: SUBTRACT
 1 NASA/INT
 1 ENV MON
 1 EOS/ERS

Use HEAO with 16 minutes data MA contact twice per orbit and one track

SPARE = one contact per orbit SA for 18 minutes with 12 minutes data and 6 minutes tracking, one contact per orbit MA for 6 minutes with no tracking.

- (8) For -75%, use -50% and

SUBTRACT
 EE
 SP

 Make HEAO use one 14 minute contact per orbit

Figures A-1 through A-7 are the Daily Loading Summaries for TDRSS loads from -75% to +75% of baseline.

C. CONFLICT ANALYZER

The Conflict Analyzer is a computer routine which accepts POCC service requests for TDRSS support and produces minute-by-minute time histories of scheduled user satellite service. Additionally, this time history is examined to identify user service contacts which are initially in conflict. Statistics characterizing the nature of those conflicts are subsequently developed.

1. Program Inputs

The Conflict Analyzer utilizes the TDRSS Planning Mission Model data as input. Satellite characteristics are expressed on a type basis.

DAILY LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/ CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
HE	1	0	1	14	13	1 00	16	208	0	0	224
HE	1	0	1	14	13	1 00	16	208	0	0	224
SS	2	0	1	6	5	1 00	0	0	14	70	84
ER	1	0	1	4	3	1 00	14	42	0	0	56
ER	2	0	1	9	8	1 00	0	0	14	112	126
ER	2	0	1	2	1	1 00	0	0	14	14	28
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
TOTALS							76	578	72	466	

Figure A-1. - 75% of Baseline Loading

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A-9

DAILY LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
HE	1	0	1	19	18	1 00	16	288	0	0	304
HE	1	0	1	19	18	1 00	16	288	0	0	304
SS	2	0	1	6	5	1 00	0	0	14	70	84
ER	1	0	1	4	3	1 00	14	42	0	0	56
ER	2	0	1	9	8	1 00	0	0	14	112	126
ER	2	0	1	2	1	1 00	0	0	14	14	28
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
SP	2	0	1	15	2	1 00	0	0	75	150	225
TOTALS							135	961	170	892	

Figure A-2. - 50% of Baseline Loading

DAILY LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
NI	1	0	1	10	9	1 00	15	135	0	0	150
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	17	16	1 00	16	256	0	0	272
HE	1	0	1	17	16	1 00	16	256	0	0	272
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EM	1	0	1	4	3	1 00	12	36	0	0	48
EM	2	0	1	4	3	1 00	0	0	12	36	48
ER	1	0	2	4	3	1 00	28	84	0	0	112
ER	2	0	2	9	8	1 00	0	0	28	224	252
ER	2	0	2	2	1	1 00	0	0	28	28	56
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
SP	1	0	1	6	5	1 00	14	70	0	0	84
SP	2	0	1	18	2	1 00	0	0	90	180	270
TOTALS							221	1459	249	1340	

Figure A-3. - 25% of Baseline Loading

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DAILY LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
NI	1	0	2	10	9	1 00	30	270	0	0	300
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	22	21	1 00	16	336	0	0	352
HE	1	0	1	22	21	1 00	16	336	0	0	352
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EM	1	0	2	4	3	1 00	24	72	0	0	96
EM	2	0	2	4	3	1 00	0	0	24	72	96
AM	1	0	1	4	3	1 00	15	45	0	0	60
AM	2	0	1	6	5	50	0	0	7	35	42
AM	2	0	1	2	1	2 00	0	0	30	30	60
ER	1	0	3	4	3	1 00	42	126	0	0	168
ER	2	0	3	2	1	2 00	0	0	84	84	168
ER	2	0	3	9	8	2 00	0	0	84	672	756
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
TOTALS							277	1933	320	1765	

Figure A-4. Baseline Loading

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A-11

DAILY LOADING SUMMARY

* NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/ CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
N1	1	0	2	10	9	1 00	30	270	0	0	300
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	22	21	1 00	16	336	0	0	352
HE	1	0	1	22	21	1 00	16	336	0	0	352
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EH	1	0	2	4	3	1 00	24	72	0	0	96
EM	2	0	2	4	3	1 00	0	0	24	72	96
AM	1	0	1	4	3	1 00	15	45	0	0	60
AM	2	0	1	6	5	50	0	0	7	35	42
AM	2	0	1	2	1	2 00	0	0	30	30	60
ER	1	0	3	4	3	1 00	42	126	0	0	168
ER	2	0	3	2	1	2 00	0	0	84	84	168
ER	2	0	3	9	8	2 00	0	0	84	672	756
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
N1	1	0	1	10	9	1 00	15	135	0	0	150
EX	2	0	1	5	4	1 00	0	0	16	64	80
AM	2	0	1	6	5	50	0	0	7	35	42
AM	1	0	1	4	3	1 00	15	45	0	0	60
HE	1	0	1	11	10	1 00	16	160	0	0	176
ER	2	0	1	2	1	2 00	0	0	28	28	56
ER	2	0	1	9	8	2 00	0	0	28	224	252
ER	1	0	1	4	3	1 00	14	42	0	0	56
SP	1	0	1	8	7	1 00	15	105	0	0	120
SP	2	0	1	7	6	1 00	0	0	15	90	105
TOTALS							352	2420	414	2206	

Figure A-5. + 25% of Baseline Loading

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A-12

DAILY LOADING SUMMARY

NUM	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACT	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL *
NI	1	0	2	10	9	1 00	30	270	0	0	300
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	22	21	1 00	16	336	0	0	352
HE	1	0	1	22	21	1 00	16	336	0	0	352
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EH	1	0	2	4	3	1 00	24	72	0	0	96
EH	2	0	2	4	3	1 00	0	0	24	72	96
AM	1	0	1	4	3	1 00	15	45	0	0	60
AM	2	0	1	6	5	1 00	0	0	7	35	42
AM	2	0	2	2	1	50	0	0	30	30	60
ER	1	0	3	4	3	2 00	42	126	0	0	168
ER	2	0	3	2	1	1 00	0	0	84	84	168
ER	2	0	3	9	8	2 00	0	0	84	672	756
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	2 00	36	108	0	0	144
EE	2	0	1	13	12	1 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
NI	1	0	1	10	9	1 00	15	135	0	0	150
NI	1	0	1	10	9	1 00	15	135	0	0	150
EX	2	0	1	10	9	1 00	0	0	16	144	160
EH	2	0	1	4	3	1 00	0	0	12	36	48
EH	1	0	1	4	3	1 00	12	36	0	0	48
ER	2	0	1	2	1	2 00	0	0	28	28	56
ER	2	0	1	9	8	2 00	0	0	28	224	252
ER	1	0	1	4	3	1 00	14	42	0	0	56
AM	2	0	2	6	5	50	0	0	15	75	90
AM	2	0	2	2	1	2 00	0	0	60	60	120
AM	1	0	2	4	3	1 00	30	90	0	0	120
HE	1	0	1	22	21	1 00	16	336	0	0	352
SP	1	0	1	7	6	2 00	30	180	0	0	210
SP	2	0	1	11	10	2 00	0	0	30	300	330
TOTALS							409	2887	509	2632	

Figure A-6. + 50% of Baseline Loading

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DAILY LOADING SUMMARY

STATION	IDENT	CLASS OF SERVICE	NO OF SATS	TIME/CONTACTS	R/F RATIO	CONTACTS/ ORBIT	FORWARD MA	RETURN MA	FORWARD SA	RETURN SA	TOTAL
NI	1	0	2	10	9	1 00	30	270	0	0	300
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
HE	1	0	1	22	21	1 00	16	336	0	0	352
HE	1	0	1	22	21	1 00	16	336	0	0	352
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
EH	1	0	2	4	3	1 00	24	72	0	0	96
EH	2	0	2	4	3	1 00	0	0	24	72	96
AM	1	0	1	4	3	1 00	15	45	0	0	60
AM	2	0	1	6	5	50	0	0	7	35	42
AM	2	0	1	2	1	2 00	0	0	30	30	60
ER	1	0	3	4	3	1 00	42	126	0	0	168
ER	2	0	3	2	1	2 00	0	0	84	84	168
ER	2	0	3	9	8	2 00	0	0	84	672	756
EE	1	0	1	6	5	2 00	23	115	0	0	138
EE	1	0	1	12	3	1 00	36	108	0	0	144
EE	2	0	1	13	12	2 00	0	0	23	276	299
ST	1	0	1	5	4	2 00	30	120	0	0	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
ST	2	0	1	10	9	1 00	0	0	15	135	150
NI	1	0	1	10	9	1 00	15	135	0	0	150
NI	1	0	1	10	9	1 00	15	135	0	0	150
EX	2	0	1	10	9	1 00	0	0	16	144	160
EH	2	0	1	4	3	1 00	0	0	12	36	48
EH	1	0	1	4	3	1 00	12	36	0	0	48
ER	2	0	1	2	1	2 00	0	0	28	28	56
ER	2	0	1	9	8	2 00	0	0	28	224	252
ER	1	0	1	4	3	1 00	14	42	0	0	56
AM	2	0	2	6	5	50	0	0	15	75	90
AM	2	0	2	2	1	2 00	0	0	60	60	120
AM	1	0	2	4	3	1 00	30	90	0	0	120
HE	1	0	1	22	21	1 00	16	336	0	0	352
SP	1	0	1	7	6	2 00	30	180	0	0	210
SP	2	0	1	11	10	2 00	0	0	30	300	330
GP	1	0	1	10	9	1 00	14	126	0	0	140
BS	1	0	1	10	9	1 00	15	135	0	0	150
CB	1	0	1	10	9	1 00	16	144	0	0	160
SS	2	0	1	6	5	1 00	0	0	14	70	84
TI	2	0	1	15	14	66	0	0	8	112	120
EX	2	0	1	10	9	1 00	0	0	16	144	160
SP	1	0	1	5	4	1 00	16	64	0	0	80
SP	2	0	1	10	9	1 00	0	0	16	144	160
TOTALS							470	3356	563	3102	

Figure A-7. + 75% of Baseline Loading

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For each satellite type, the length of data contact, number of data contacts per orbit, and number of tracking contacts per orbit are specified. For each satellite within a particular type, the orbital height and name are specified. Table A-1 summarizes the input data for the baseline load. The first field identifies the satellite number. Field two, three, four and five specify the satellite name, type and service required. The fifth field is a control mechanism by which TDRSS Concept I or II can be specified. For Concept II, field five would indicate all SA, whereas field four retains the characteristic shown for reference purposes. The sixth field specifies the satellite orbital height. The length of return link service (length of data) and the number of times return link service is required per orbit is specified in fields seven and eight, respectively. All satellites were assumed to be tracked at least once per orbit. This track was assumed to occur simultaneously with a data contact. The last field in Table A-1 indicates the number of tracking contacts in excess of the number of data contacts per orbit. Because of the uncertainty in the duration of TDRSS tracking contacts at the time of program definition, this parameter was left as an input variable.

For modeling purposes, some satellites, such as Environmental Monitor (ENV MON), had to be included more than once. This became necessary when service was required on both MA and SA links.

2. Program Functions

The Conflict Analyzer has three basic functions; Scheduling, Conflict Identification, and Statistical Characterization.

a. Scheduling

The scheduling function utilized a random service allocation technique to simulate requests for service at specific times. On an independent satellite-by-satellite and orbit-by-orbit basis, service requirements were derived and scheduled within specific constraints. Each satellite is processed, in turn, as follows. An orbit initiation time is calculated. This time can be less than or equal to zero (start of simulation time). If the name of the satellite currently being processed is the same as the

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TABLE A-1. CONFLICT ANALYZER INPUTS

1	INT1	TYP1	MA	MA	94	9	1	0
2	INT2	TYP1	MA	MA	94	9	1	0
3	GRV PROBE	TYP1	MA	MA	104	9	1	0
4	BESS	TYP1	MA	MA	96	9	1	0
5	COSM BKRD	TYP1	MA	MA	92	9	1	0
6	HEAD	TYP2	MA	MA	92	21	1	0
7	ERS 1	TYP3	MA	MA	94	3	1	0
8	ERS 2	TYP3	MA	MA	94	3	1	0
9	ERS 3	TYP3	MA	MA	94	3	1	0
10	ENV MON 1	TYP3	MA	MA	92	3	1	0
11	ENV MON 2	TYP3	MA	MA	92	3	1	0
12	AEM	TYP3	MA	MA	97	3	1	0
13	SPACE TELE	TYP4	MA	MA	97	4	2	0
14	AE	TYP5	MA	MA	125	5	2	0
15	AE	TYP6	MA	MA	125	11	1	0
16	ENV MON 1	TYP7	SA	SA	92	3	1	0
17	ENV MON 2	TYP7	SA	SA	92	3	1	0
18	TIROS	TYP8	SA	SA	120	14	1	0
19	EXT XRAY	TYP9	SA	SA	92	9	1	0
20	SEASAT	TYP10	SA	SA	101	5	1	0
21	AE	TYP11	SA	SA	125	12	2	0
22	AEM	TYP12	SA	SA	97	5	1	2
23	ERS 1	TYP13	KA	SA	94	2	2	3
24	ERS 2	TYP13	KA	SA	94	2	2	3
25	ERS 3	TYP13	KA	SA	94	2	2	3
26	SPACE TELE	TYP14	SA	SA	97	9	2	0

name of a previously processed satellite, their orbit times are forced to correspond. Next the length of orbit null time is defined (time neither TDRS can see the user spacecraft). Finally the portion of orbit which can be viewed by TDRS EAST, TDRS WEST or both TDRSs is determined. Data service is then scheduled. A random number is drawn to determine the start time of this service. Checks are made to insure that the data service does not extend into the null zone. Additionally, if more than one data contact is required per orbit (for example the Space Telescope) these contacts are guaranteed to be separated by $1/3$ to $1/2$ the orbit. For the first minute of the contact both forward link and return link are used (acquisition). The forward link is also used for a time equal to length of track. The program assumes tracking is accomplished on each data contact. If more tracking contacts are required per orbit than data contacts they are scheduled following all data scheduling. A random number is drawn as a candidate track start time. Checks are then made to ensure the minute preceeding and the minute following the duration of track are not scheduled. Thus all scheduled events in an orbit are separated by at least one minute.

b. Conflict Identification

When the total schedule for the time period of interest (input variable) has been developed in the above manner, the Conflict Analyzer scans each minute. A determination is made on a minute-by-minute basis of whether the number of satellites requesting service exceeds the TDRSS resources. This comparison is performed independently for each TDRS as well as for each type of service offered. Conflict minutes are identified for analysis. If conflict resolution is used, the raw schedule and identified conflicts are passed to the Zero-Order Conflict Resolver.

c. Statistical Characterization

Three fundamental statistics are obtained from the Conflict Analyzer: average number of conflicts, average number of minutes per conflict, and distributions of free-time intervals. The Analyzer can be run in interactive steps to obtain statistical results. Outputs from

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conflict identification provide the basis for determining the number of conflicts per run and average length of conflict per run. These statistics are developed by standard techniques. Free-time interval distributions are determined as follows. The schedule is divided into one hour increments. Each hour is then analyzed to extract the periods during which both a forward and return link is available simultaneously. Distributions are then calculated which describe the ability to provide unscheduled service of a specified duration within the next hour. This computation is accomplished as follows:

$$P = 1 - (1 - P^*)^{60 - N}$$

P = probability of being able to start a desired contact so as to finish not later than one hour from present

P^* = probability of being able to start desired length of service to a given channel

$$P^* = 1 - (1 - \dot{P})^C,$$

C = number of channels in total resource

\dot{P} = probability of being able to start service on a given minute on a given channel

$$\dot{P} = \sum_{i=N}^{60} (i - N) x_i / CM$$

i = interval size

x_i = number of occurrences of interval size i in total schedule minutes (M)

N = minimum time of desired service

3. Program Outputs

Five basic outputs are provided by the Conflict Analyzer.

- (1) Schedule Time History
- (2) Conflict Minute Summary
- (3) Minutes in Conflict
- (4) Channel Conflict Identification
- (5) Number of Conflicts

Figure A-8 is the first 60 minutes of a 12 hour schedule generated by the Conflict Analyzer. The numbers across the top of the display correspond to the satellites as numbered in Figure A-1. The first column identifies the schedule minute. The + and - identify which portion of the orbit is in view of TDRS WEST (+) and TDRS EAST (-). Blank zones indicate the portion of the orbit in view of both TDRSs. The D's signify return link service (normally Data). The B's indicate the times when Both forward and return link are being used simultaneously. The N's indicate the Null zones where the satellite can not be seen by either TDRS. T's indicate Tracking contacts.

Figure A-9 displays the Conflict Minute Summary. The average length of conflicts (in minutes) on each link is provided for each TDRS. Figure A-10 provides the detailed information associated with each conflict minute. The vertical line separates MA and SA users. The numbers other than minute and satellite identifiers are for internal program use. The first conflict minute identified (minute 155 of the schedule) indicates a conflict on the SA return link for TDRS WEST. Three demands are made for this resource while the capability exists to satisfy only two (Concept 1). Figure A-11 provides a summary of channel resource conflicts. For each schedule minute the number of requests for use of MA or SA channels is provided. Where resources are exceeded, an asterisk appears.

D. ZERO-ORDER CONFLICT RESOLVER

The Zero-Order Conflict Resolver was developed to assess the benefits derived from the use of very elementary schedule optimization techniques. Additionally, only the most basic conflicts are attempted to be resolved. The only conflicts for which the Resolver attempts resolution are those in which the total number of user satellites exceeds the resource by one. For example, on either MA forward link, the Resolver will attempt resolution on conflicts involving no more than two users. Similarly, for Concept 1 the Resolver only considers conflicts on SA links involving three

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NTIME = 1		LTIME = 126				LTRACK = 1																					
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
1	-	+	+D		+	+	-	-	-	N	N					N	N	-	+	-	-D		-	-	-	-	
2	-	+	+D		+	+	-	N	-	N	N	-		-	-	N	N	-	+	N	-D		-	N	-	-	
3	-	+	+D		+	+	-	N	-B	N	N	-		-B	-	N	N	-	+	N	-D		-	N	-	-	
4	-	+	+D		+	+	-	N	-D	N	N	-		-D	-	N	N	-	+	N	-D		-	N	-	-	
5	-	+B	+D		+	+	-	N	-	N	N	-		-D	-B	N	N	-	+	N	-D	-T	-	N	-	-	
6	-	+D	+		+	+	-	N	-	N	+	-B		-D	-D	N	+	-	+	N	-D		-	N	-B	-	
7	-	+D	+		+	+	-	N	-	N	+	-D		-D	-D	N	+	-	+	N	-D		-	N	-D	-	
8	-	+D	+		+	+	-B	N	-	+	+	-D		-	-D	+	+	-	+	N	-D		-	N	-	-	
9	-	+D	+		+B	+	-D	N	-	+	+	-		-	-D	+	+	-	+	N	-		-	N	-	-	
10	-	+D	+		+D	+	-D	N	-	+	+	-		-	-D	+	+	-	+B	N	-		-	N	-	-	
11	-	+D	+		+D	+	-	N	-	+	+	-		-	-D	+	+	-	+D	N	-		-	+	N	-	
12	-	+D			+D	+	-	+	N	+	+	-		-	-D	+	+	-	+D	N	-		-	+	N	-	
13	-	+D			+D	+	-	+	N	+	+	-		-	-D	+	+B	-	+D	N	-		-	+B	N	-	
14	-				+D	+	-	+	N	+	+	-		-	-D	+	+D	-	+D	+	-		-	+D	N	-	
15	-B				+D	+	-	+	N	+	+	-		-	-D	+	+D	-	+D	+	-		-	+	N	-	
16	-D				+D	+	-	+	N	+	+	-		-	-	+	+	-	+D	+	-		-	+	N	-	
17	-D				+D	+	-	+	N	+	+	-		-	-	+	+	-	+D	+	-		-	+	N	-	
18	-D				+	+	N	+	N	+	+	-		-	-	+	+	-	+D	+	-		-	+	N	-	
19	-D	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
20	-D	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
21	-D	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
22	-D	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
23	-D	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
24	-	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
25	-	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
26	-	-			+	+	+	+	N	+	+	-		-	-	+	+	-	+	+	-		-	+	N	-	
27	-	-			+	+	+	+	N	+	+	-		-B	-	+	+	N	+	+	-		-	+	N	-	
28	-	-			+	+	+	+	+	+	+	-		-D	-	+D	+	N	+	+	-		-	+	+	-	
29	N	-			+	+	+	+	+	+	+	-		-D	-	+	+	N	+	+	-		-	+	+	-	
30	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-T	+	+	+	-	
31	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
32	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
33	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
34	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
35	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
36	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
37	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
38	N	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
39	+	-			+	+	+	+	+	+	+	-		-	-	+	+	N	+	+	-	-	+	+	+	-	
40	+	-			+	+	+	+	+	+	+	-		-	-	+	+	+	+	+	-	-	+	+	+	-	
41	+	-			+	+	+	+	+	+	+	N		-	-	+	+	+	+	+	-	N	+	+	+	-	
42	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
43	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
44	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
45	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
46	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
47	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
48	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
49	+	-			+	+	+	+	+	+	+	N	N		-	+	+	+	+	+	-	N	+	+	+	N	
50	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
51	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
52	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
53	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
54	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
55	+	-			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
56	+	N			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
57	+	N			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
58	+	N			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	
59	+	N			+	+	+	+	+	+	+	N	N		N	+	+	+	+	+	-	N	+	+	+	N	

Figure A-8. Schedule Time History

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RUN TITLE= BASE LINE LOAD, CONCEPT 1

```

*****
*                                     *
*          WEST                      EAST          *
*                                     *
*****
*          *          *          *          *          *          *          *
*          MA      *      SA      *      MA      *      SA      *      *
*          *          *          *          *          *          *          *
*****
*          *          *          *          *          *          *          *
* F      *      R      *      F      *      R      *      F      *      R      *
*          *          *          *          *          *          *          *
*****
1          0          0          0          6          1          0          0          1

```

Figure A-9. Conflict Minute Summary

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TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
155	+	-		-	-	-	+	+	+		-B		-	-	-		-	+D	-	+	-		+	+D	+B	-	
	1	21	11	21	21	21	1	1	1	11	24	11	21	21	21	11	21	3	21	1	21	11	1	3	4	21	
156	+B	-		-	-	-	+	+	+	-	-D		-	-	-		-	+D	-	+B	-		+	+	+D	-	
	4	21	11	21	21	21	1	1	1	21	23	11	21	21	21	21	21	3	21	4	21	11	1	1	3	21	
297	-	+D	-	+	+	+	-	-	-	+	+	-	+	-	-		+	+B	+D	+	-	-D	-	-	-T	-	+D
	21	3	21	1	1	1	21	21	21	1	1	21	1	21	21		1	4	3	1	21	23	21	21	22	21	3
363		N	-B	-	-	-	+	-		-	-	-B	-	+	+		-	-	-	+B	+	+	-	+	-	-	
	11	15	24	21	21	21	1	21	11	21	21	24	21	1	1	21	21	21	4	1	1	21	1	21	11	21	
576	-	+		N	+	+D	-	-	-	+	+	-	+	+	+		+	+B	-	+D	-	+D	-	-	-	+	
	21	1	11	15	1	3	21	21	21	1	1	21	1	1	1	1	1	4	21	3	21	3	21	21	21	1	
577	-	+		N	+	+D	-	-	-	+	+	-	+	+	+		+	+D	-	+D	-B	+D	-	-	-	+	
	21	1	11	15	1	3	21	21	21	1	1	21	1	1	1	1	1	3	21	3	24	3	21	21	21	1	
578	-	+		N	+	+D	-	-	-	+	+	-	+	+	+		+	+D	-	+D	-D	+D	-	-	-	+	
	21	1	11	15	1	3	21	21	21	1	1	21	1	1	1	1	1	3	21	3	23	3	21	21	21	1	
673	-	+		N	+	+D	-	-	-	+	+D	-	+	-	-D		+	+	-D	+D		-	-	-	-T	+	
	21	1	11	15	1	3	21	21	21	1	3	21	1	21	23	1	1	23	3	11	21	21	21	22	24	1	

Figure A-10. Minutes in Conflict

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TIME	WEST				EAST			
	MA		SA		MA		SA	
	F	R	F	R	F	R	F	R
0	0	1	0	0	0	0	0	1
1	0	1	0	0	0	0	0	1
2	0	1	0	0	0	0	0	1
3	0	1	0	0	2	2	0	1
4	0	1	0	0	0	2	0	1
5	1	2	0	0	1	3	1	2
6	0	1	0	0	1	3	1	2
7	0	1	0	0	0	3	0	2
8	0	1	0	0	1	3	0	1
9	1	2	0	0	0	2	0	0
10	0	2	1	1	0	2	0	0
11	0	2	0	1	0	1	0	0
12	0	2	0	1	0	1	0	0
13	0	2	2	3	0	1	0	0
14	0	1	0	3	0	1	0	0
15	0	1	0	2	1	2	0	0
16	0	1	0	1	0	1	0	0
17	0	1	0	1	0	1	0	0
18	0	0	0	1	0	1	0	0
19	0	0	0	0	0	1	0	0
20	0	0	0	0	0	1	0	0
21	0	0	0	0	0	1	0	0
22	1	1	0	0	0	1	0	0
23	0	1	0	0	0	1	0	0
24	0	1	0	0	0	0	1	1
25	0	0	0	0	0	0	0	1
26	0	0	0	0	0	0	0	1
27	0	0	1	1	1	1	0	1
28	0	0	0	1	0	1	0	1
29	0	0	0	1	0	1	0	1
30	0	0	0	0	0	1	1	2
31	0	0	0	0	0	0	0	1
32	0	0	0	0	0	0	0	1
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	1	1	0	0	0	0
37	0	0	0	1	0	0	0	0
38	0	0	0	0	0	0	0	0
39	0	0	1	1	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
44	1	1	0	0	0	0	0	0
45	1	2	1	1	0	0	0	0
46	0	2	0	1	1	1	0	0
47	0	1	0	0	0	1	0	0

Figure A-11. Channel Conflict Identification

users. Where such conflicts are identified, one or both of two resolution strategies is used.

The first strategy determines whether one of the user's contacts contributing to the conflict lies totally within the zone that can be viewed by either TDRS. If so, this contact is switched from the scheduled TDRS to the other. Suppose user 1 had a data dump occurring totally within the transition zone scheduled for TDRS WEST. If User 1 was contributing to a zero-order conflict, this contact would be switched to TDRS EAST. No attempt to switch back is made if the conflict is not resolved.

The second resolution strategy shifts service backward in time when conflicts are identified. Conflict Analyzer outputs indicated that the length of track was the principal driver for conflicts generated on forward links. The resolution scheme then employed a technique which moved one user's service backward in time an interval equal to the length of track for zero-order conflicts occurring on the forward links. An arbitrary three minutes was chosen for the backward movement of return link services. Limitations of the program prevented use of time periods exceeding three minutes.

The Resolver utilized the outputs of the conflict identifier portion of the Conflict Analyzer. The Resolver produces outputs comparable to those previously shown for the Conflict Analyzer. An additional output (Figure A-12) identifies the conflicts for which resolution was and was not attempted.

E. SYSTEM QUEUING MODEL (SQM)

For the purpose of analyzing the information flows of the NOCC in a quantitative manner, a system queuing model was made operational on BDM's computer facilities. This model was designed to calculate all statistically significant parameters that can describe information flow networks and job-shop processes. It relies on the construction of a program-compatible network model comparable to the system under study. Proper

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A-25

WEST EAST									
MA SA MA SA									
TIME	F	R	F	R	F	R	F	R	
0	0	1	0	0	0	0	0	1	
1	0	1	0	0	0	0	0	1	
2	0	1	0	0	0	0	0	1	
2	1	2	2	1	20				
4 TO RESOLVE A CONFLICT AT TIME 4 A TRACK FROM SAT 9 OF TYPE -B WAS SHIFTED BACK 1 SQUARES FROM TIME 4									
4 - +D	+	+	-	N	-B	N	N	-	+
21	1	3	11	1	1	21	15	24	15 15
2			0	1	0	0	1	1	0 1
3			0	1	0	0	1	2	0 1
4			0	1	0	0	0	2	0 1
5			1	2	0	0	1	2	1 2
6			0	1	0	0	1	3	1 2
7			0	1	0	0	0	3	0 2
8			0	1	0	0	1	3	0 1
9			1	2	0	0	0	2	0 0
10			0	2	1	1	0	2	0 0
11			0	2	0	1	0	1	0 0
12			0	2	0	1	0	1	0 0
1	2	2	3	2	2				
14 TO RESOLVE A CONFLICT AT TIME 14 A TRACK FROM SAT 17 OF TYPE +B WAS SHIFTED BACK 3 SQUARES FROM TIME 14									
14 - +D	-	+	D	+	-	+	N	+	+
21	3	11	21	3	1	21	1	15	1 1
10			0	2	2	2	0	2	0 0
11			0	2	0	2	0	1	0 0
12			0	2	0	2	0	1	0 0
13			0	2	1	2	0	1	0 0
14			0	1	0	2	0	1	0 0
15			0	1	0	1	1	2	0 0
16			0	1	0	1	0	1	0 0
17			0	1	0	1	0	1	0 0
18			0	0	0	1	0	1	0 0
19			0	0	0	0	0	1	0 0
20			0	0	0	0	0	1	0 0
21			0	0	0	0	0	1	0 0
22			1	1	0	0	0	1	0 0
23			0	1	0	0	0	1	0 0
24			0	1	0	0	0	0	1 1
25			0	0	0	0	0	0	0 1
26			0	0	0	0	0	0	0 1
27			0	0	1	1	1	1	0 1
28			0	0	0	1	0	1	0 1
29			0	0	0	1	0	1	0 1
30			0	0	0	0	0	1	1 2
31			0	0	0	0	0	0	0 1
32			0	0	0	0	0	0	0 1
33			0	0	0	0	0	0	0 0

Figure A-12. Conflict Resolver Output

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analogs to random or distributed arrivals, nodes and branches, queue lengths and wait-times etc. must be drawn for the successful use of the model.

Initially, the TDRSS acquisition process was modeled using the SQM. Comparisons were made of alternative automatic reacquisition signaling methods, utilizing the acquisition procedures and their associated probabilities as defined in the TDRSS Performance Specification (Reference 4). As the study progressed, discussion with NASA personnel indicated that TDRSS acquisition procedures had solidified. Thus, this aspect of the Operations Control Analysis was discontinued.

APPENDIX B
TDRSS ORBITAL SUPPORT REQUIREMENTS

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APPENDIX B
TDRSS ORBITAL SUPPORT REQUIREMENTS

Table B-1 of this appendix specifies the baseline load orbital support requirements for missions serviced by TDRSS utilized in Phase I of the TDRSS Operations Control Analysis Study. For each mission, the number of satellites, type of service (for TDRSS Concept I), and the number and duration of service contacts are identified on a per orbit basis.

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TABLE B-1. TDRSS ERA BASELINE MISSION MODEL

<u>MISSION</u>	<u>SERVICE</u>	<u>SERVICE REQUIREMENT (PER ORBIT)</u>
NASA/INT (2)	MA	ONE 10 MINUTE DATA PLUS TRACKING
GRAVITY PROBE (1)	MA	ONE 10 MINUTE DATA PLUS TRACKING
BESS - A, B, C, D (1)	MA	ONE 10 MINUTE DATA PLUS TRACKING
COSMIC BKGD (1)	MA	ONE 10 MINUTE DATA PLUS TRACKING
HEAO (1)	MA	ONE 1 MINUTE TRACK TWO 21 MINUTE DATA
SEASAT-B (1)	SA	ONE 6 MINUTE DATA PLUS TRACKING
TIROS (1)	SA	ONE 15 MINUTE DATA PLUS TRACKING EVERY 1-1/2 ORBITS
EXT X-RAY (1)	SA	ONE 10 MINUTE DATA PLUS TRACKING
ENV MON (2)	MA SA	ONE 3 MINUTE R/T DATA ONE 4 MINUTE P/B DATA PLUS TRACKING
AEM (TYPICAL) (1)	SA SA MA	ONE 6 MINUTE P/B DATA PLUS TRACKING EVERY 2 ORBITS TWO 1 MINUTE TRACK ONE 3 MINUTE R/T DATA
EOS/ERS (3)	SA SA MA	TWO 9 MINUTE P/B DATA PLUS TRACKING TWO 1 MINUTE TRACKS ONE 3 MINUTE R/T DATA
EE (1)	MA MA SA	TWO 6 MINUTE R/T DATA PLUS TRACKING ONE 12 MINUTE R/T DATA PLUS TRACKING TWO 12 MINUTE P/B DATA
ST (1)	MA SA SA	TWO 5 MINUTE R/T DATA (1 TRACK) ONE 10 MINUTE P/B DATA (1 TRACK) ONE 10 MINUTE P/B DATA

() = NUMBER OF SIMULTANEOUS MISSIONS

R/T = REAL TIME

P/B = PLAYBACK

APPENDIX C
REPRESENTATIVE GSTDN SUPPORTED MISSION

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APPENDIX C
REPRESENTATIVE GSTDN SUPPORTED MISSION

Table C-1 of this appendix provides a compilation of planned and expected GSTDN supported missions from 1979 to 1982. Planned orbits and orbital requirements are presented (where known) to indicate classes of missions scheduled for the GSTDN. These missions were utilized in the formulation of the parameterized GSTDN Mission Model used in Phase I of the TDRSS Operations Control Analysis Study.

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TABLE C-1. TDRSS ERA MISSION MODEL FOR GSTDN (TYPICAL MISSIONS)

<u>NAME</u>	<u>TENTATIVE LAUNCH DATE</u>	<u>PLANNED ORBIT (KM)</u>	<u>COMMENTS</u>
GEOPAUSE-B	1982	POLAR, NEAR SYNCHRO- NOUS ALTITUDE	PLAYBACK ONLY;
HIGH ALT-B	1982	HELIOCENTRIC	PLAYBACK ONLY, 540 HRS/Q
LAE-C	1982	HELIOCENTRIC	CONTINUOUS SUPPORT
SEOS-A	1982	NEAR SYNCHRONOUS	24 HR DEDICATED ETC
STORMSAT	1982	SYNCHRONOUS	9m DEDICATED ETC
SERT III	1981	SYNCHRONOUS	5 HRS/DAY
SPHINX	1981	SYNCHRONOUS	8 HRS/DAY
AE-SPEOS	1981	SYNCHRONOUS	2160 HRS/Q
EE-B	1980	300 X 30,000	90° INCLINATION
LPO (AND RELAY)	1980	LUNAR	24 HR COVERAGE
CP - ENCKE	1980	HELIOCENTRIC	2160 HRS/Q
COS-BKD	1980	SYNCHRONOUS	
IUE	1979	NEAR SYNCHRONOUS	9m DEDICATED ETC
ISEE-A,B	1979	280 X 140,000	REALTIME/PLAYBACK; NEAR CONTINUOUS
ISEE-C	1979	LAGRANGIAN POINT BETWEEN SUN AND EARTH	26m ANTENNA MANDATORY

SOURCE: MISSION SUPPORT SUMMARY AND NETWORK FORECAST, STDN NO. 803.2, FEBRUARY 1976;
NETWORK SUPPORT CAPABILITY PLAN, FEBRUARY 1976; TDRSS PLANNING MISSION MODEL,
JULY 1975.

APPENDIX D
ALTERNATIVE TASK CONTROL METHODOLOGIES

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APPENDIX D
ALTERNATIVE TASK CONTROL METHODOLOGIES

A. INTRODUCTION

This appendix identifies the alternative control methodologies defined for each of the four network operations tasks. The salient differences between the alternatives for each task are specified in terms of the allocation of workload, responsibility and authority between the NOCC and users. Additionally, the interface differences among the alternatives are identified.

B. SCHEDULING

Four basic alternatives were identified for control of the scheduling process. Figures D-1 through D-4 identify the information flow associated with each alternative. Figures D-1 and D-2 represent the concept bounding alternatives, centralized and decentralized respectively. Two basic assumptions were inherent in all scheduling alternatives. The first was that GSFC POCC's do not generate a "conflict free" schedule which is submitted to the schedulers. All initial POCC requests are submitted to the scheduler directly to increase scheduling flexibility. The second assumption also supports scheduling flexibility. Service requests are assumed to take one or a combination of the following forms:

- Generic
- Specific
- Quasi-Generic

Generic requests are those which must be periodically scheduled but the time at which the event occurs is, within specified rules, not critical. For example, a generic request may be represented by "three tracking contacts every orbit." As long as these contacts are "appropriately" spaced in time, the exact time of their occurrence is not critical.

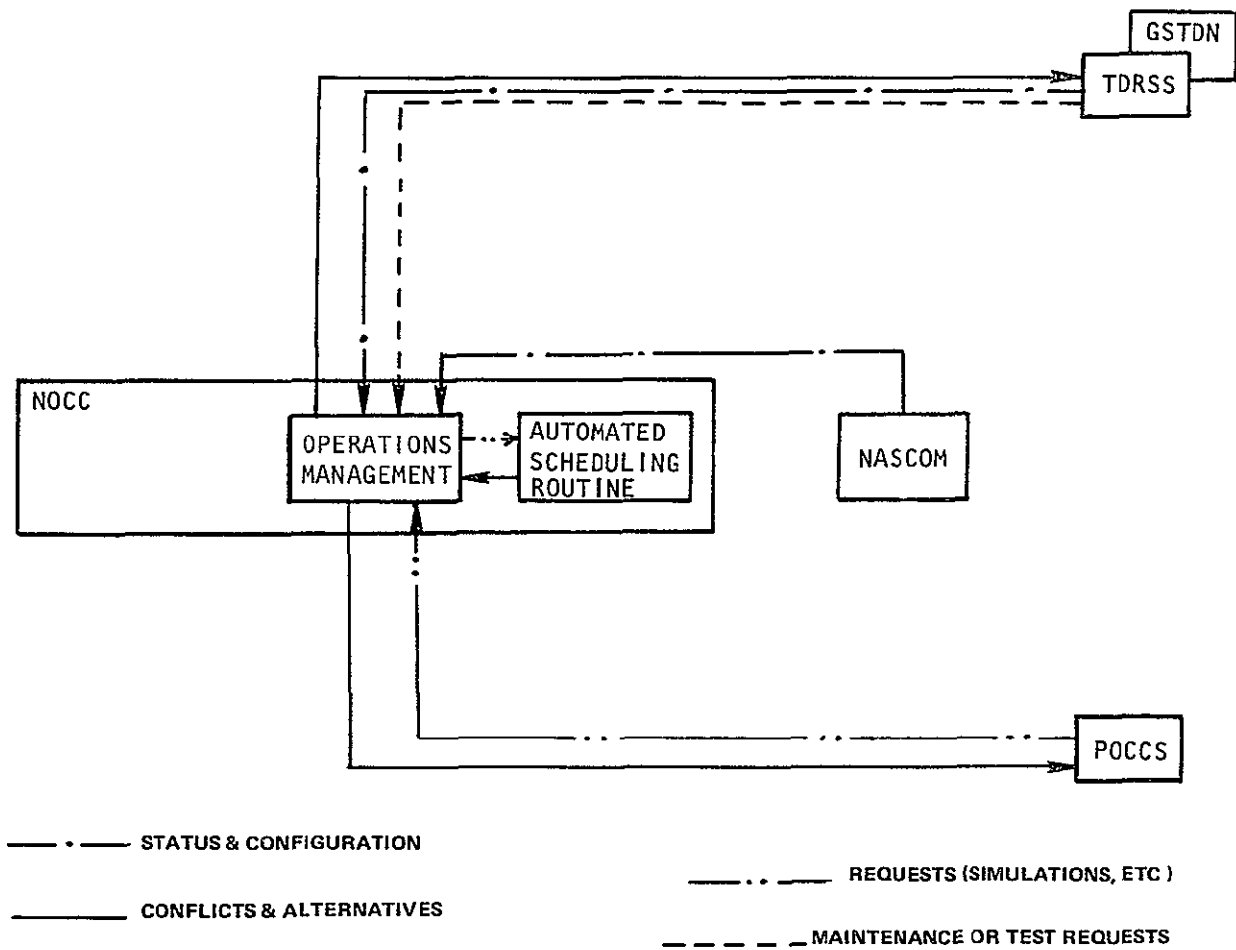


Figure D-1. Information Flow for Centralized Control of Scheduling (Alternative 1)

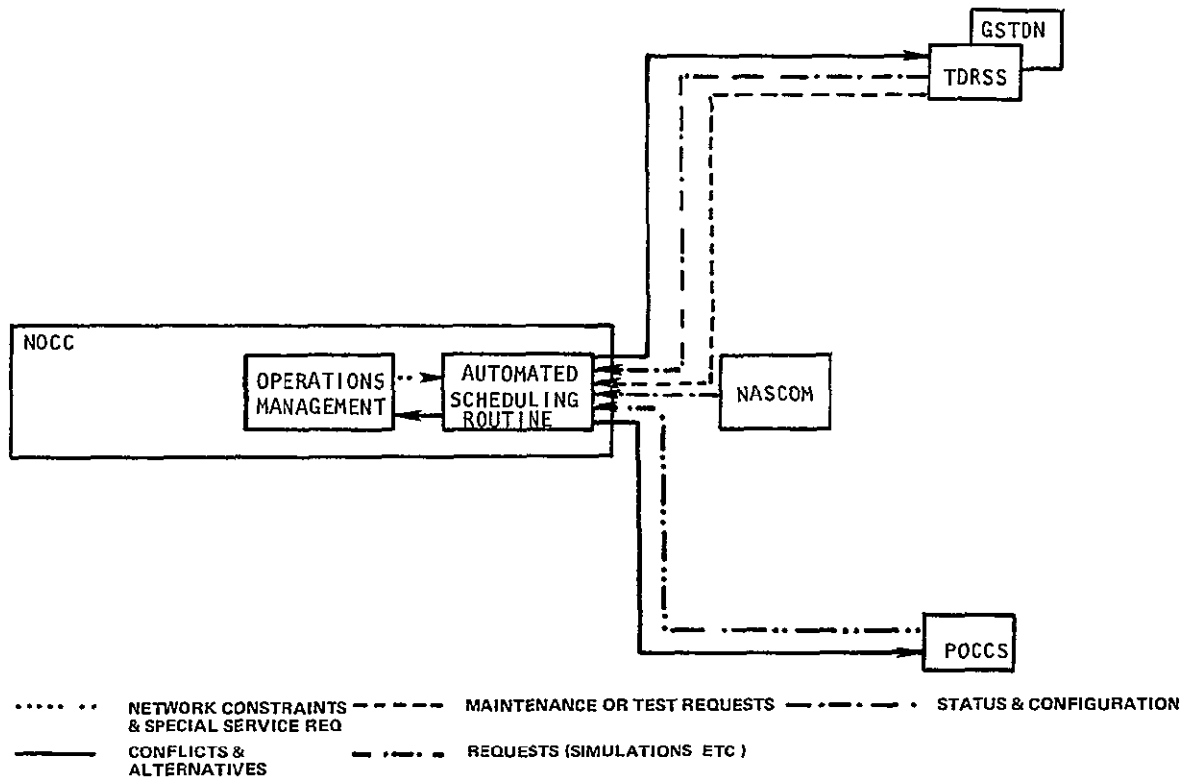


Figure D-2. Information Flow for Decentralized Control of Scheduling (Alternative 2)

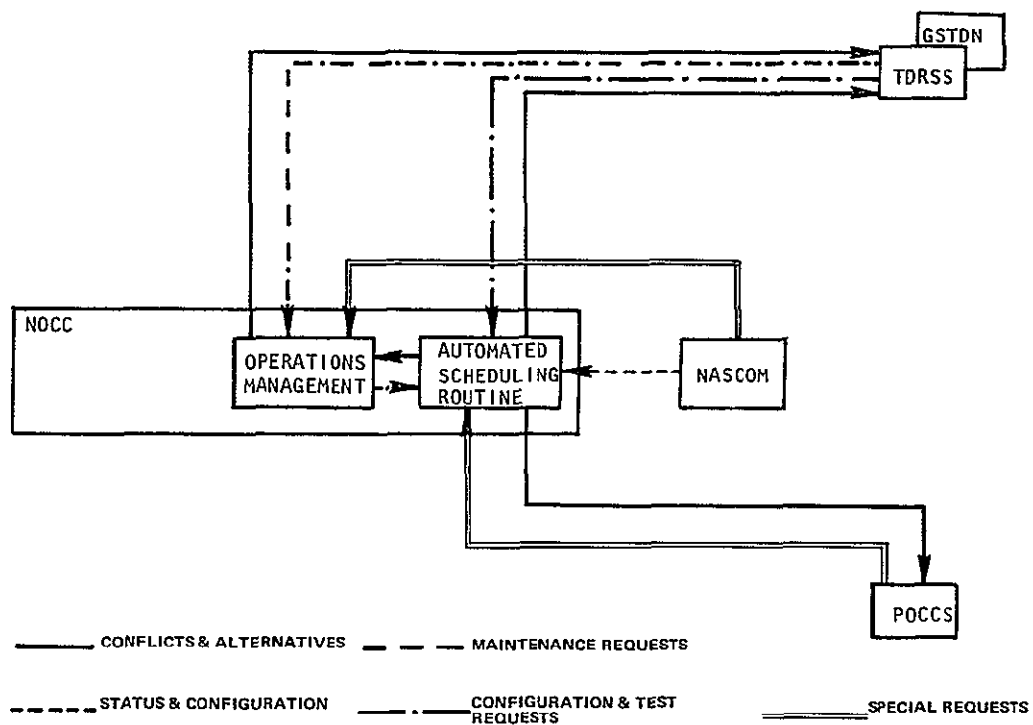


Figure D-3. Information Flow for Matrix Control of Scheduling (Alternative 3)

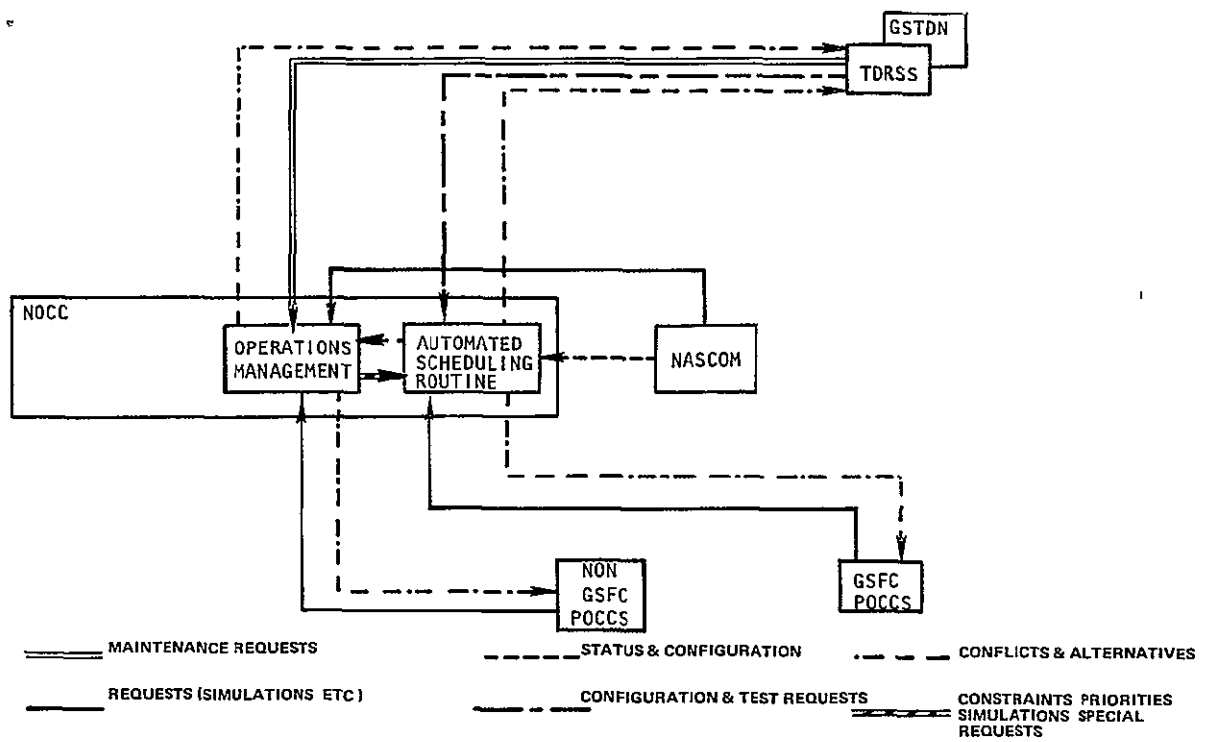


Figure D-4. Information Flow for Matrix Control of Scheduling (Alternative 4)

Specific requests represent the other end of the request spectrum. These events require scheduling at the precise time indicated. Quasi-generic requests are specific requests with increments about their initiation times. For example, a request for a return link data dump support may specify a desired start time plus or minus 'X' minutes.

The results from the Conflict Analyzer indicated that very few conflicts were generated at the baseline load if each satellite and all service types (tracking, commanding, data relay etc.) were assigned the same priority. Therefore, a request class priority scheme was adopted as part of the baseline scheduling approach. In this scheme, all satellites are assumed to have a single priority. However, specific, quasi-generic and generic requests would have the indicated priority ranking. Specific requests would always be scheduled first, quasi-generic second, and generic last. It was also postulated that the request type and hence priority could change as a function of time. For example, periodic preventive maintenance (PM) could be considered initially as generic requests, but, as the time since the last PM increases, the next required PM activity assumes a more specific nature. In the limit, if the required PM has reached the maximum length of time since last performed, the ASR considers the PM request as specific.

1. Centralized

Each element within, and utilizing, the network submits requests to the NOCC for scheduling in the centralized approach (Figure D-1). These requests are for routine service, simulations, maintenance, launch support, etc. Major status and configuration conditions are also provided to the NOCC by STDN elements for scheduling constraint purposes. As implied by the information flow, the actual work, responsibility and authority associated with the task of scheduling is vested in the NOCC. In this alternative the only interface with the Automatic Scheduling Routine (ASR) is within the NOCC. The interface with NOCC operations management can take two forms, automated or manual. The latter is represented by current STDN procedures wherein requests for service are made on

paper or possibly verbally by phone. The former may be conceptualized as an automated accounting system. POCCs/users and STDN elements would, via interactive terminals, specify scheduling events. At a predetermined point in time the NOCC would then cause these events to be input to the ASR. The requestors would then be able to modify or change their requests until the NOCC defined ASR EPOCH. This approach does have the disadvantage of potentially requiring large numbers of interactive terminals and additional NOCC hardware and software.

Upon completion of ASR, execution conflicts are identified. Additionally, the ASR identifies alternative time periods wherein the service may be accommodated. The NOCC then notifies the elements in conflict and supervises the conflict resolution. This interface is seen as taking both verbal and text form. The text, in form of TTY, for GSFC remote elements would provide a backup for the verbal information exchange.

2. Decentralized

The decentralized approach distributes the workload, responsibility and authority for scheduling among the network elements and users. In this alternative, each element capable of scheduling an event or providing constraints to scheduling is given interactive access to the ASR. As each request is received by the ASR, a response is provided indicating either that the event has been scheduled as requested or that there is a conflict. For conflicts, each element in the conflict is identified. Additionally, alternatives for scheduling the service of the element generating the initial conflict are provided. It is then the responsibility of the elements in the conflict to successfully resolve the issue. As seen from the Conflict Analyzer program these conflicts can be severe at high loads (e.g., involving 6-8 POCCs for periods up to 15 minutes). In these situations, a mutually accepted priority scheme may be necessary to assist in conflict resolution. Without such a scheme, conflict resolution could assume long time frames.

In this alternative, the NOCC is considered in the same level as other elements. Operations management can request the scheduling of tests, simulations or special activities it deems necessary.

A salient advantage of this approach is the speed with which the POCCs can assess the impact on their service of large system perturbations such as spacecraft emergencies. When the schedule is severely impacted by such perturbations, the ASR can optimally realign the schedule and display it for POCC review. The POCCs also have the capability to assess the impacts on their service if they desire to change this optimal allocation. Of course, a drawback is the requirement for interactive terminals in each element's location.

3. Matrix

Two matrix approaches were defined. The first (Figure D-3) retains decentralized POCC service scheduling but centralizes maintenance scheduling. This alternative was developed to allow the imposition of "network" considerations in maintenance scheduling. The POCC/ASR interfaces are supported by interactive terminals, as before. The NOCC/STDN ground station interface has the same options as described in centralized scheduling control. Although this approach does allow direct application of network constraints to maintenance scheduling, these constraints could also be input to the ASR by operations management thus allowing the ground stations to interact directly with the ASR. The advantage of this interactive capability is again in the speed with which the stations know their maintenance is scheduled as requested or must be revised.

The second approach (Figure D-4) centralized non-GSFC POCC scheduling, in addition to maintaining centralized maintenance scheduling and decentralized GSFC POCC scheduling. The POCCs were segmented because of the specialized request of and network utilization for the missions associated with the non-GSFC POCC's.

C. SYSTEM INTEGRITY

The alternative approaches to each component of system integrity are identified herein. The approaches for determination of routine system integrity are identified in Figures D-5 and D-6. Interfaces are automated

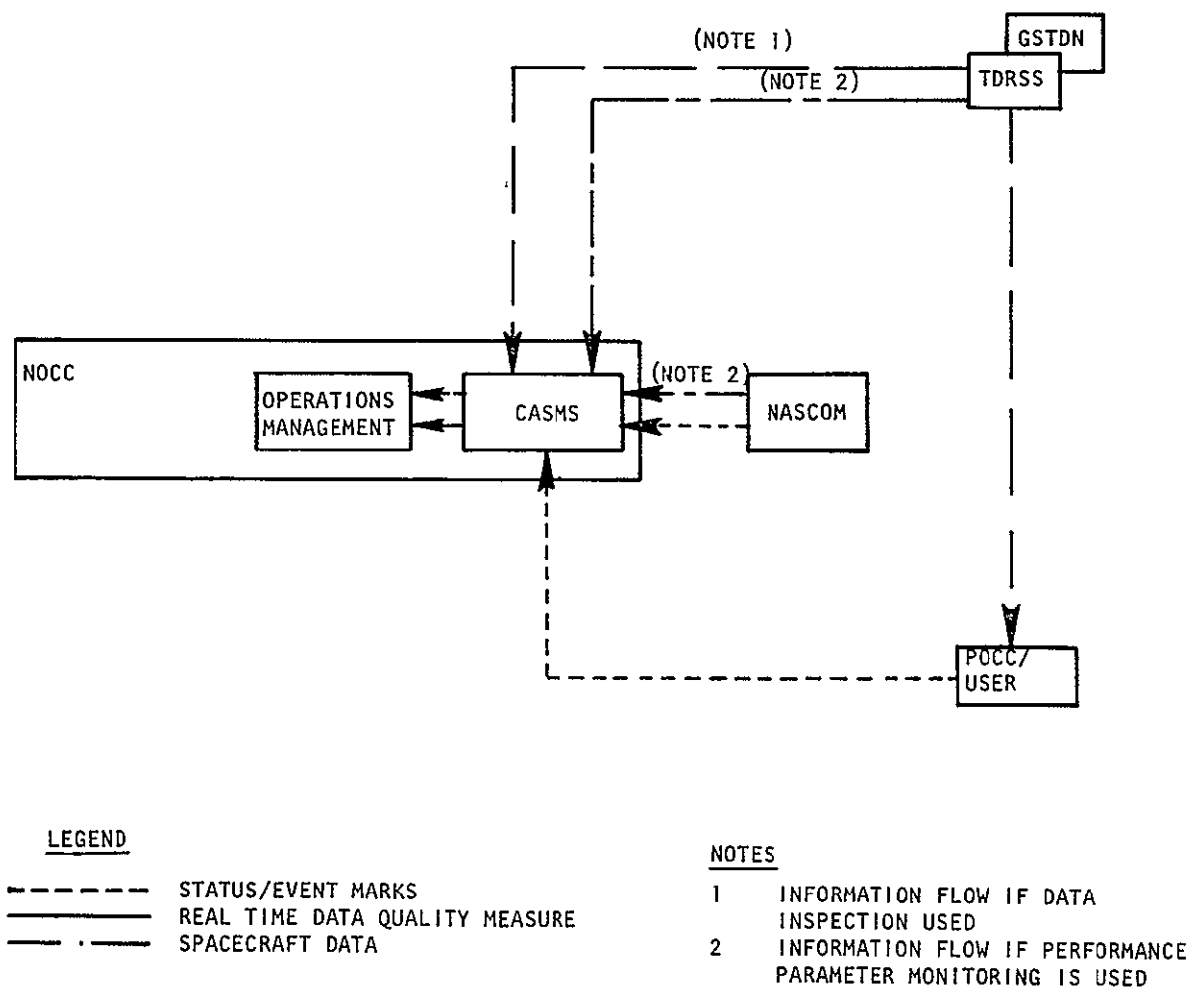
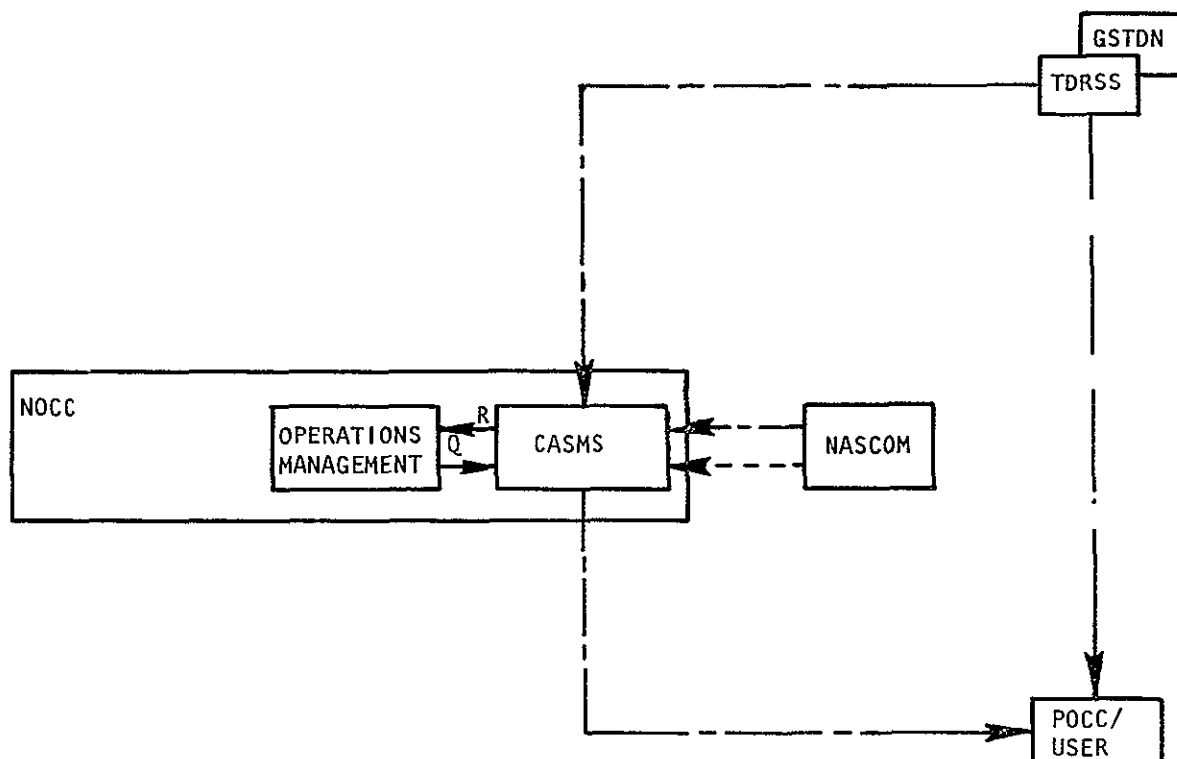


Figure D-5. Routine Integrity Assessment Information Flow (Centralized Control)



LEGEND

- DATA FLOW
- - - - - STATUS/EVENT MARKS
- — — — — PERFORMANCE PARAMETERS (IF USED)
- - - - - SAMPLED PERFORMANCE PARAMETER VALUES (IF USED)

Figure D-6. Routine Integrity Assessment Information Flow (Decentralized Control)

via CASMS. A fundamental difference in the two approaches resides in the areas of data inspection. Since the POCs, in the decentralized approach, inspect their respective data on a real time basis, obtaining data inspection information from CASMS was not deemed relevant.

As part of the analysis associated with routine system integrity the impacts of using pre and post contact link testing were investigated. Table D-1 and Figure D-7 indicate the impacts derived in the number of conflicts and free time intervals when link testing is used.

The centralized and decentralized approach to network tests is provided in Figures D-8 and D-9 respectively.

The alternative approaches to centralized and decentralized control of network simulations is provided in Figures D-10 through D-15. Since there are a large number of ways that network elements and users can be configured in network simulations, three representative cases were developed. These cases represent network simulations involving users, STDN ground stations and the SOC. Figures D-10 through D-12 identify the information flow for the centralized control of these three cases. Figures D-12 through D-15 identify the information flow for the decentralized control of these three cases.

D. MALFUNCTION IDENTIFICATION, ISOLATION AND RESTORATION

The centralized and decentralized approaches for this task are shown in Figures D-16 through D-17 respectively. As in previous task methodologies, CASMS supports the automated nature of the interfaces.

E. ROUTINE SERVICE

The centralized approach to routine service is shown in Figures D-18, and D-19 provides the information flow associated with centralized control when the shuttle is in orbit. The decentralized approach is shown in Figure D-20.

TABLE D-1
EFFECT OF LINK TESTING
ON CONFLICTS

TRACKING TIME	CONCEPT I		CONCEPT II	
	TOTAL CONFLICTS		TOTAL CONFLICTS	
	TEST	NO TEST	TEST	NO TEST
3	93	63	77	54
5	130	98	105	85

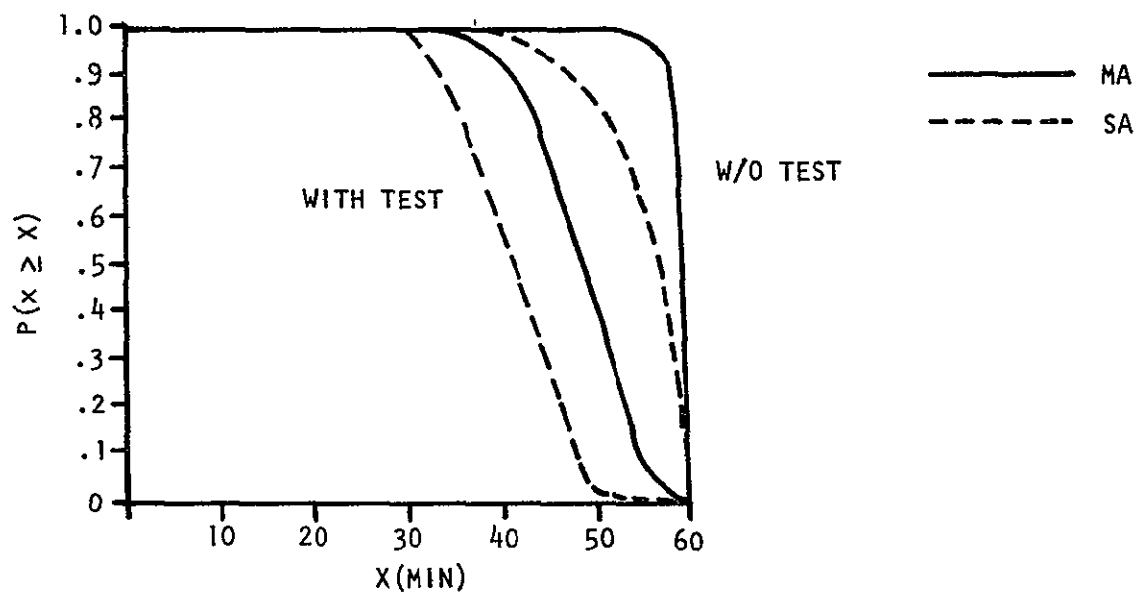
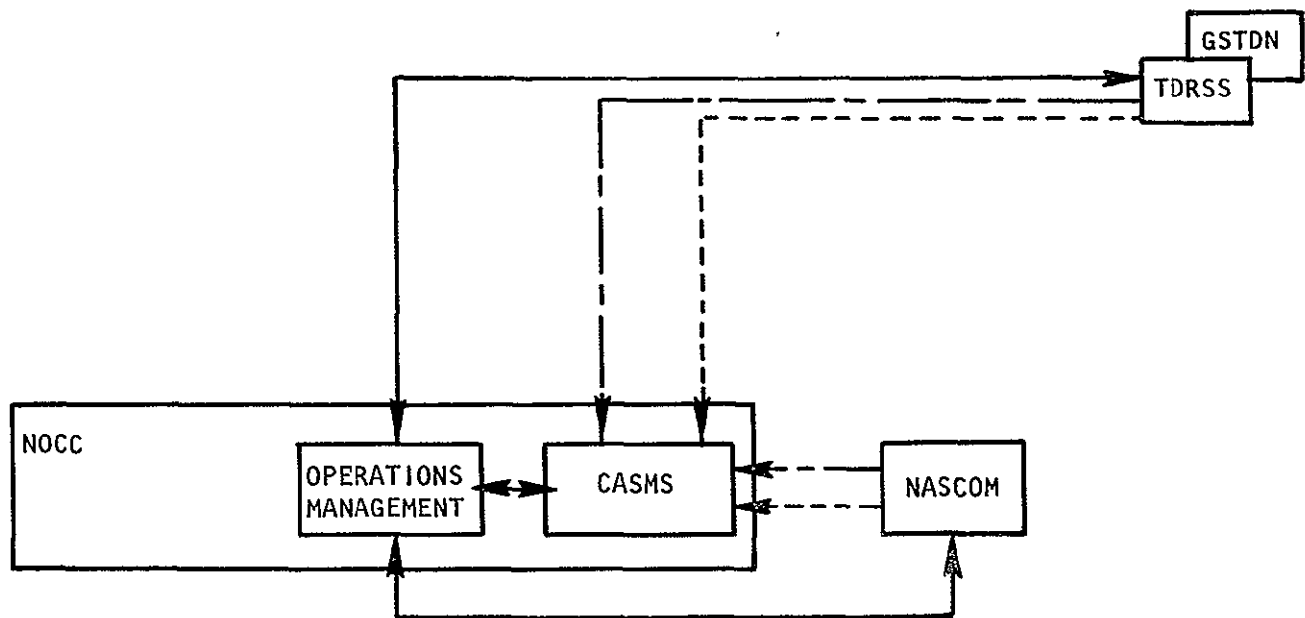


Figure D-7. Effect of Link Testing on Available Slots of Free Time (Concept 1)



LEGEND

- NOCC DIRECTIVES AND COORDINATION
- - - - PERFORMANCE PARAMETERS (IF USED)
- STATUS/EVENT MARKS

Figure D-8. Special Test Information Flow (Centralized Control)

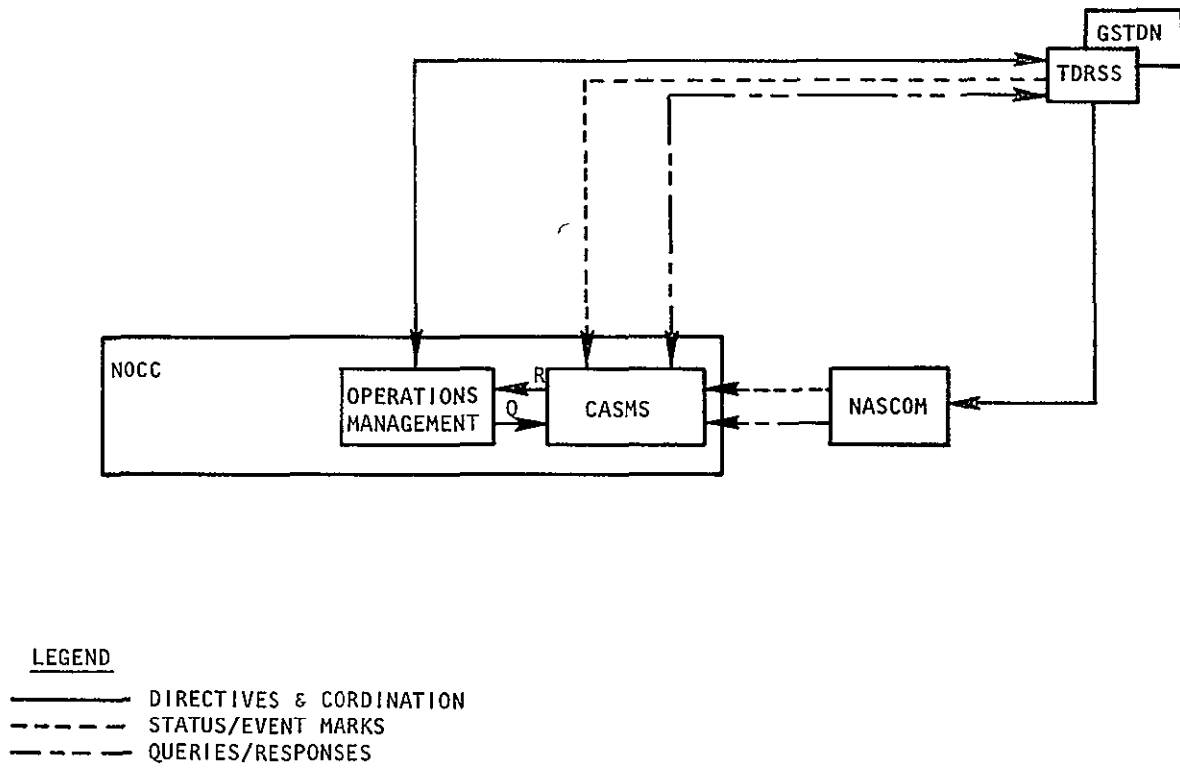
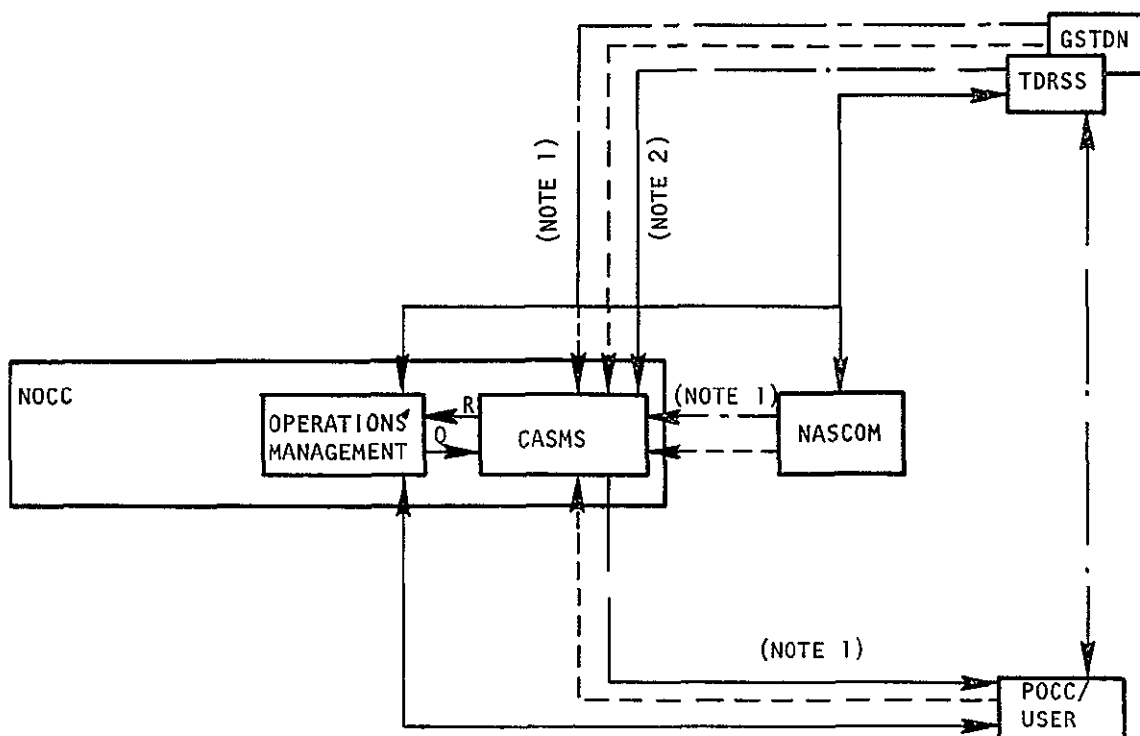


Figure D-9. Special Test Information Flow
(Decentralized Control)



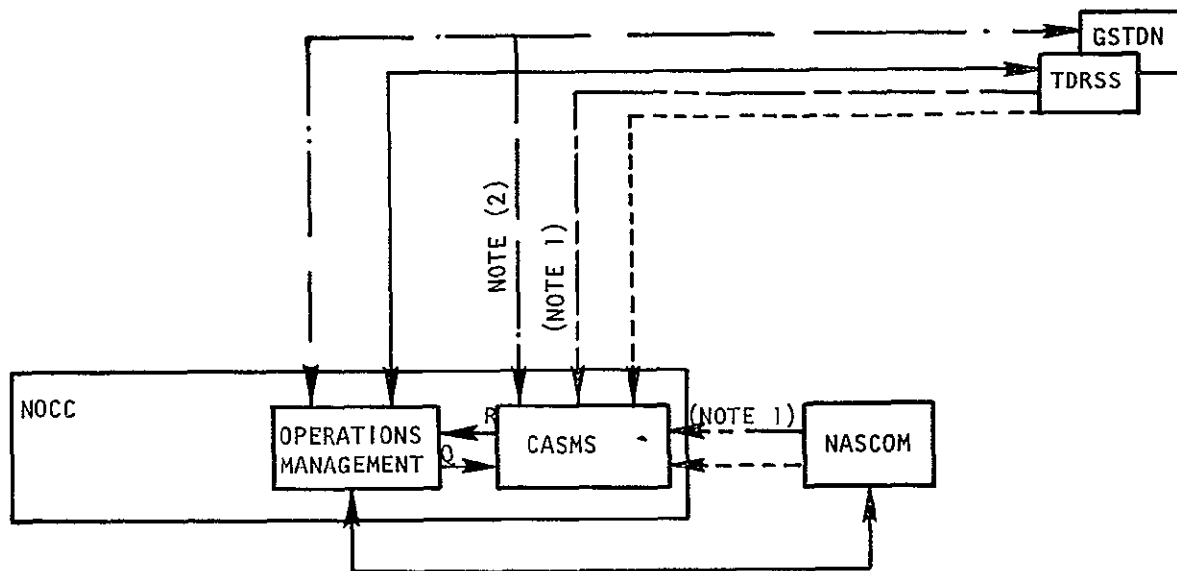
LEGEND

- NOCC DIRECTIVES AND COORDINATION
- STATUS/EVENT INDICATORS
- . - . - . SIMULATION DATA FLOW

NOTES

1. INFORMATION FLOW IF PERFORMANCE PARAMETER MONITORING IS USED
2. DATA FLOW IF DATA INSPECTION IS USED

Figure D-10. Network Simulation Information Flow For Simulations Conducted for Users (Centralized Control)



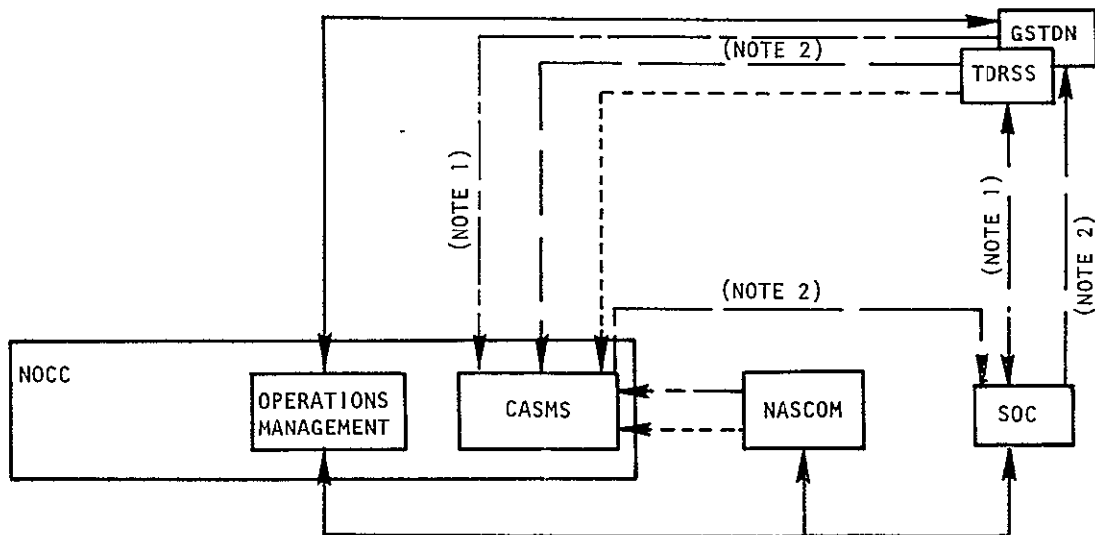
LEGEND

- NOCC DIRECTIVES AND COORDINATION
- STATUS/EVENT INDICATORS
- SIMULATION DATA FLOW

NOTES

- 1 INFORMATION FLOW IF PERFORMANCE PARAMETER MONITORING IS USED
- 2 DATA FLOW IF DATA INSPECTION IS USED

Figure D-11. Network Simulation Information Flow For Simulations Involving STDN Ground Stations (Centralized Control)



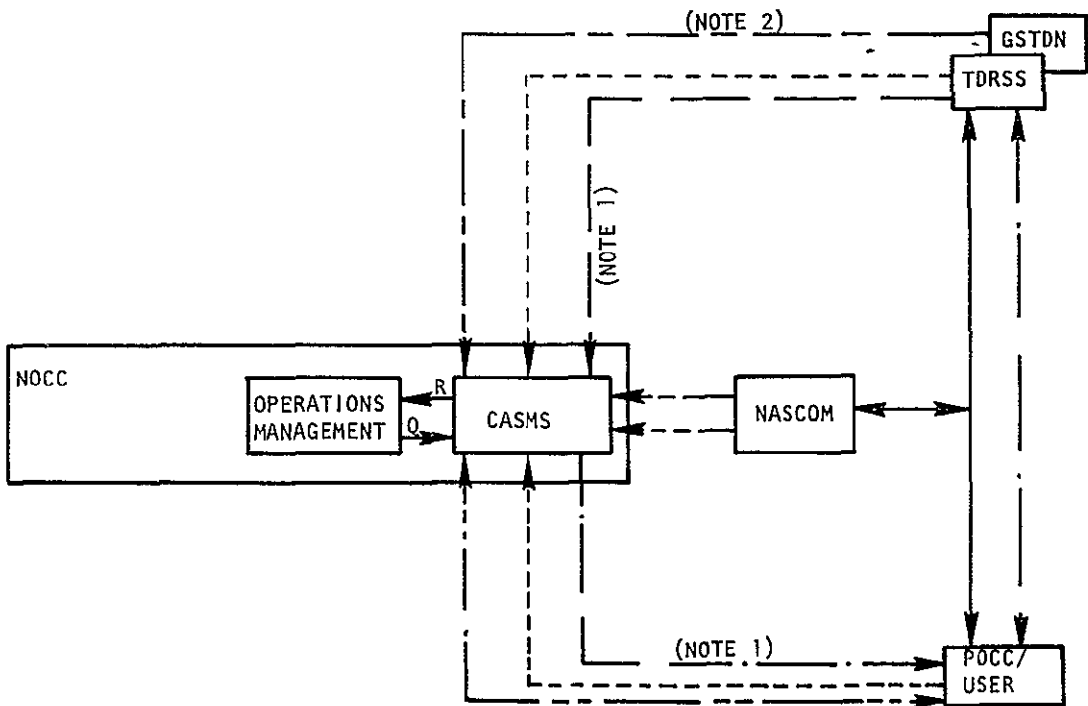
LEGEND

- NOCC DIRECTIVES AND COORDINATION
- - - - - STATUS/EVENT INDICATORS
- SIMULATION DATA FLOW

NOTES

- 1 INFORMATION FLOW IF PERFORMANCE PARAMETER MONITORING IS USED
- 2 DATA FLOW IF DATA INSPECTION IS USED

Figure D-12. Network Simulation Information Flow for Simulations of Network Responses Utilizing the SOC (Centralized Control)



LEGEND	NOTES
———— NOCC DIRECTIVES AND COORDINATION	1 INFORMATION FLOW IF PERFORMANCE
----- STATUS/EVENT INDICATORS	PARAMETER MONITORING IS USED
- . - . - . SIMULATION DATA FLOW	2 DATA FLOW IF DATA INSPECTION
----- QUERY/RESPONSES	IS USED

Figure D-13. Network Simulation Information Flow for Simulations Conducted by Users (Decentralized Control)

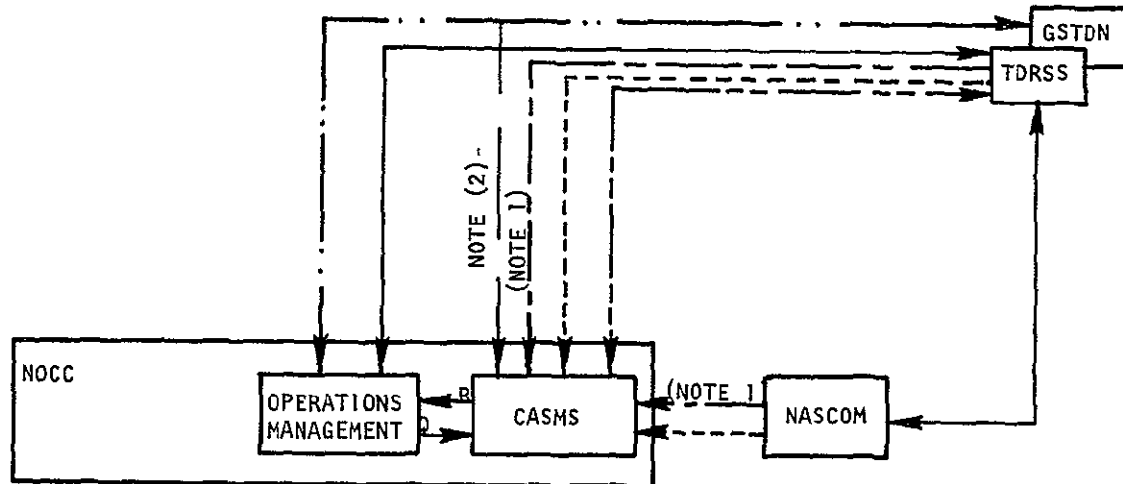


Figure D-14. Network Simulation Information Flow for Simulations Involving STDN Ground Stations (Decentralized Control)

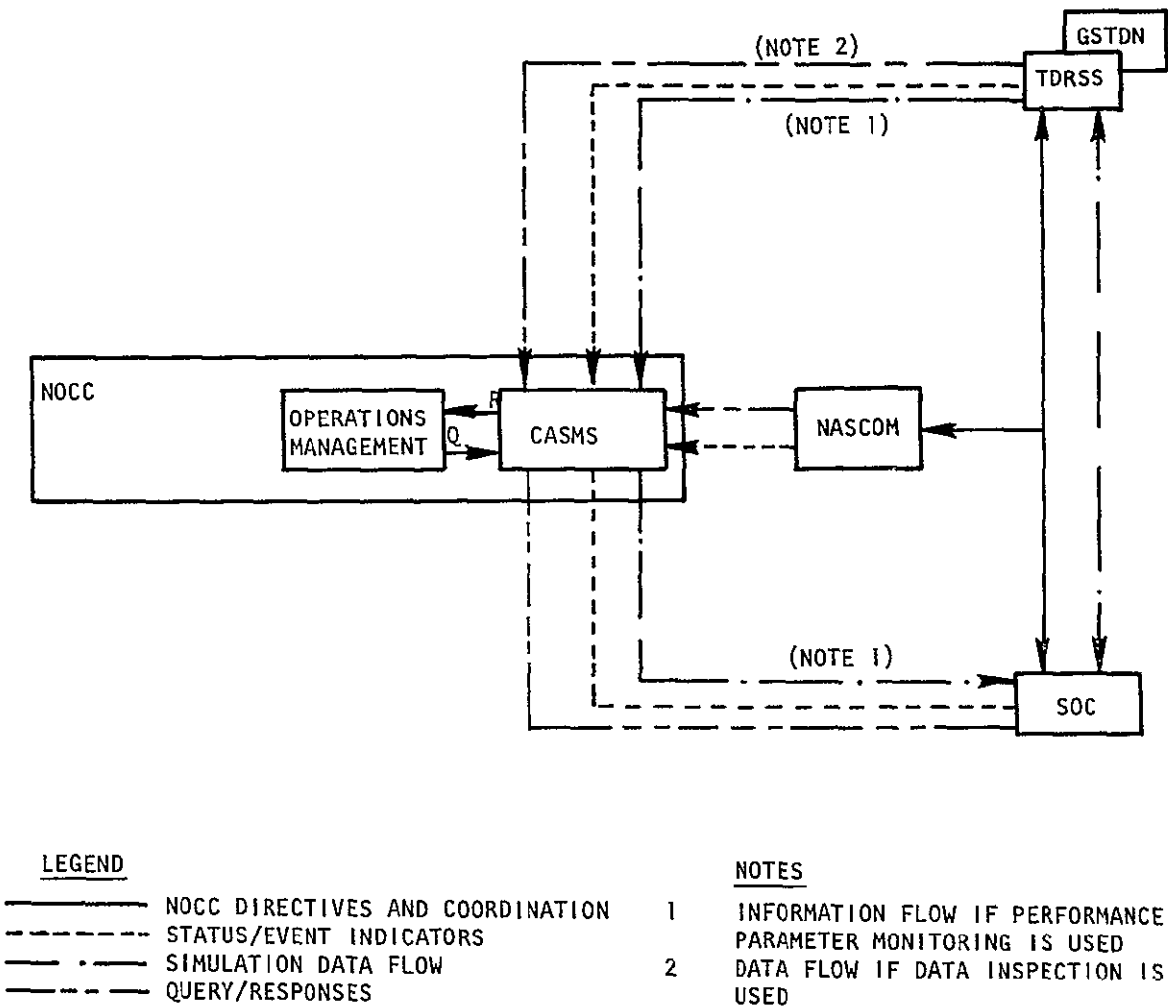


Figure D-15. Network Simulation Information Flow for Simulations of Network Responses Utilizing the SOC (Decentralized Control)

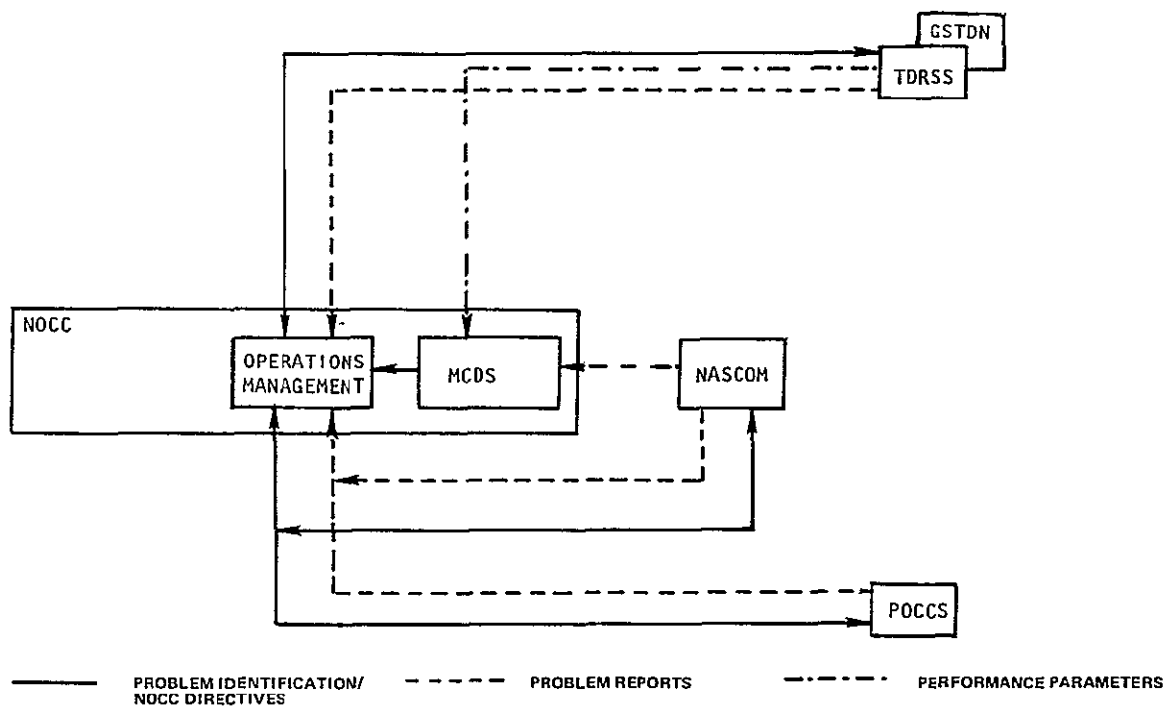


Figure D-16. Malfunction Identification, Isolation and Restoration Information Flow (Centralized)

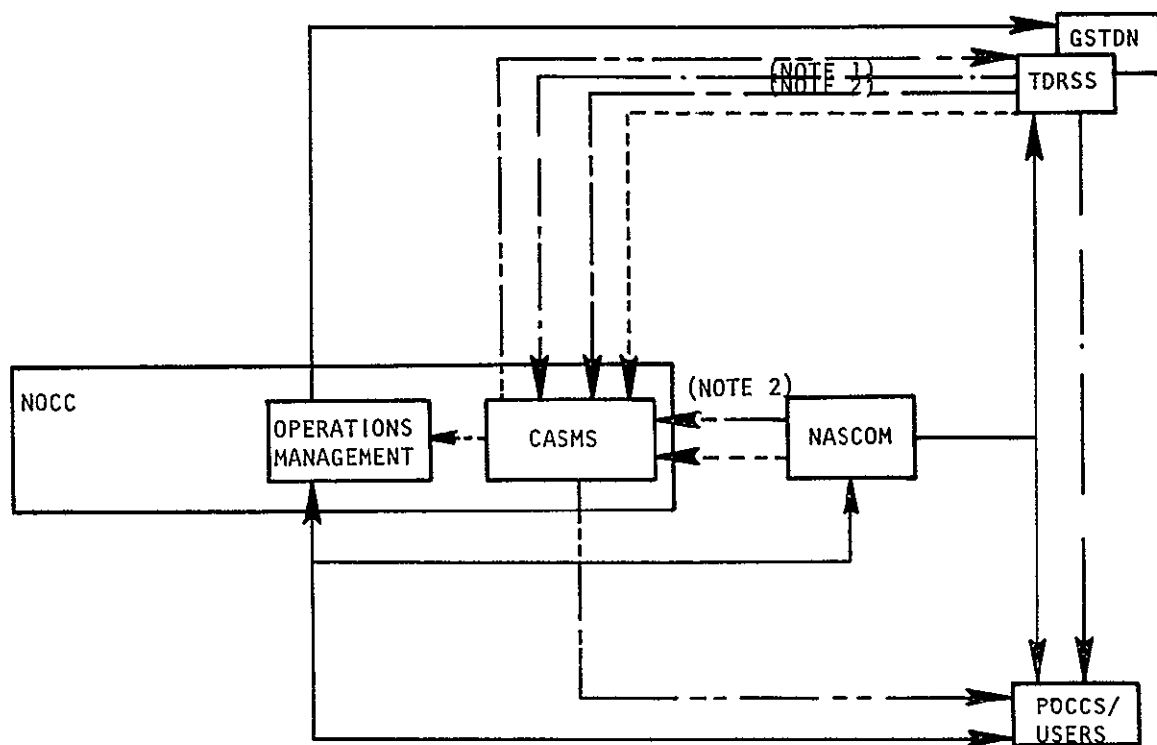
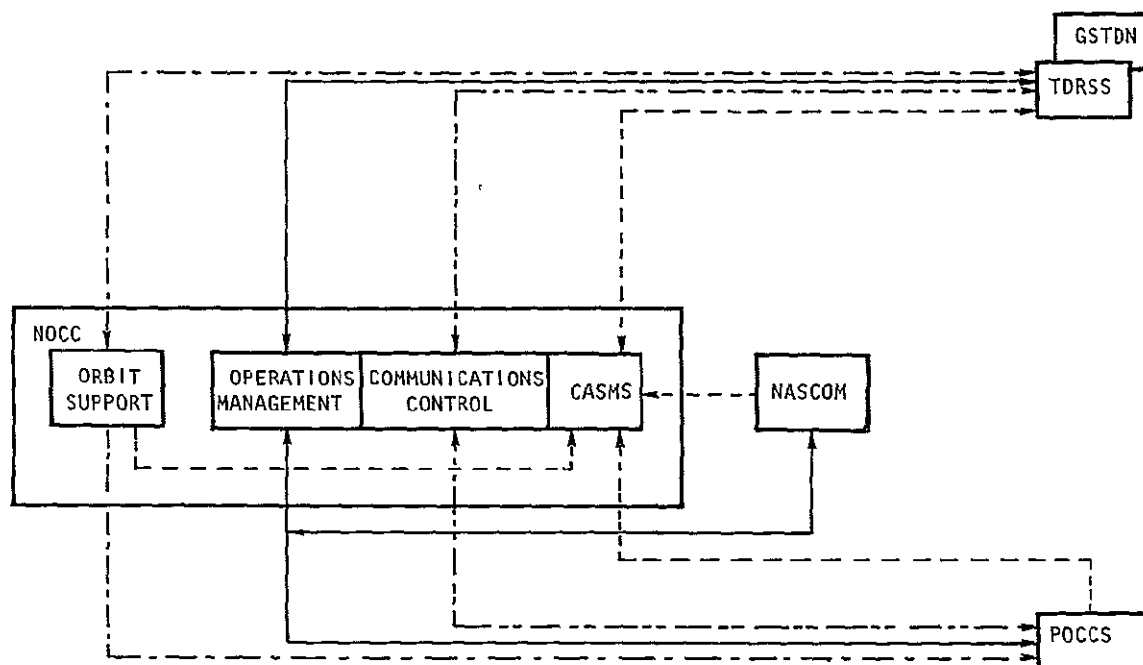


Figure D-17. Malfunction Identification, Isolation and Restoration Information Flow (Decentralized Control)



- LEGEND
- STATUS/EVENT MARKS
 - S/C VECTORS/TDRS LOCATION DATA
 - NOCC DIRECTIVES AND COORDINATION
 - FORWARD/RETURN LINK DATA FLOW

Figure D-18. Routine Service Information Flow (Centralized Control)

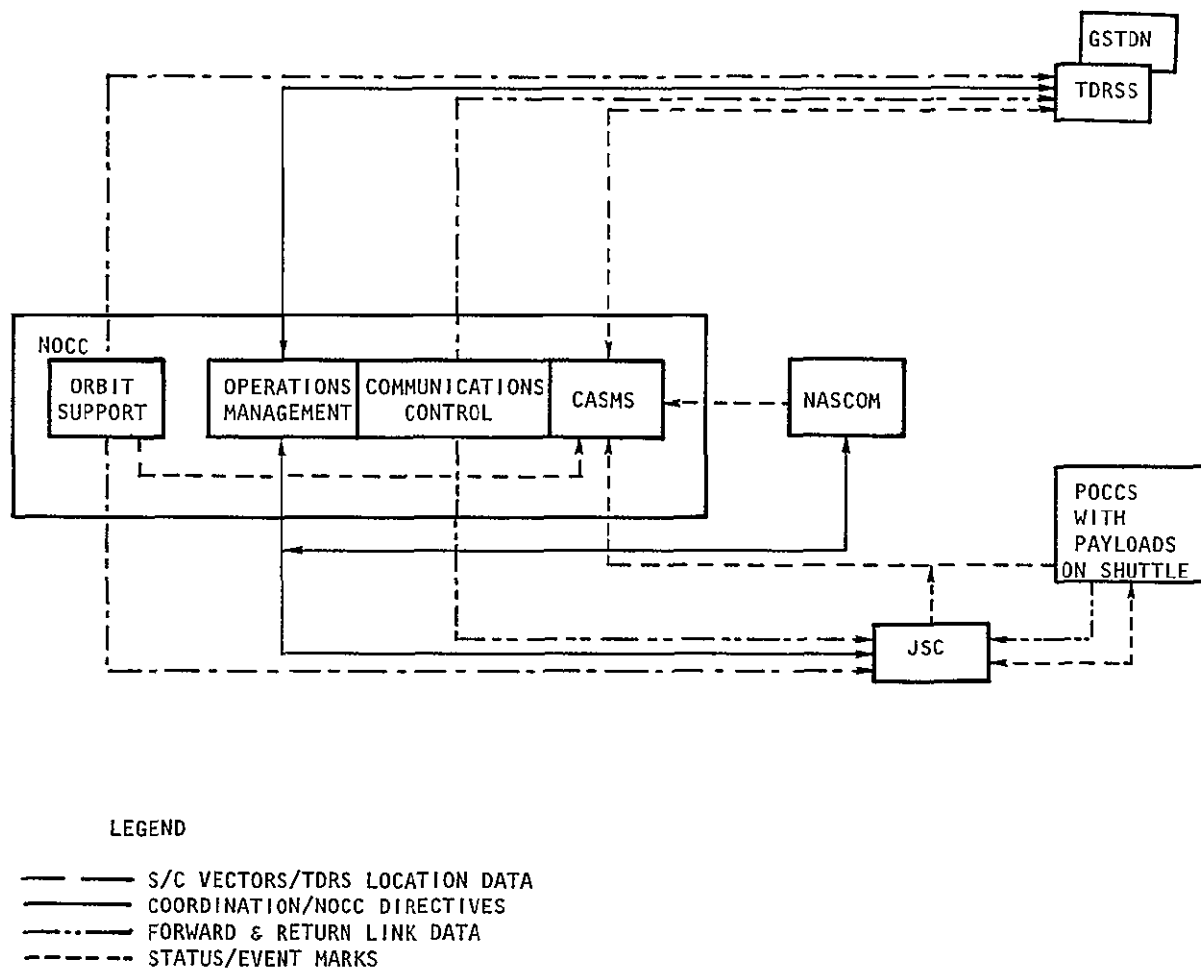


Figure D-19. Routine Service Information with Shuttle (Centralized Control)

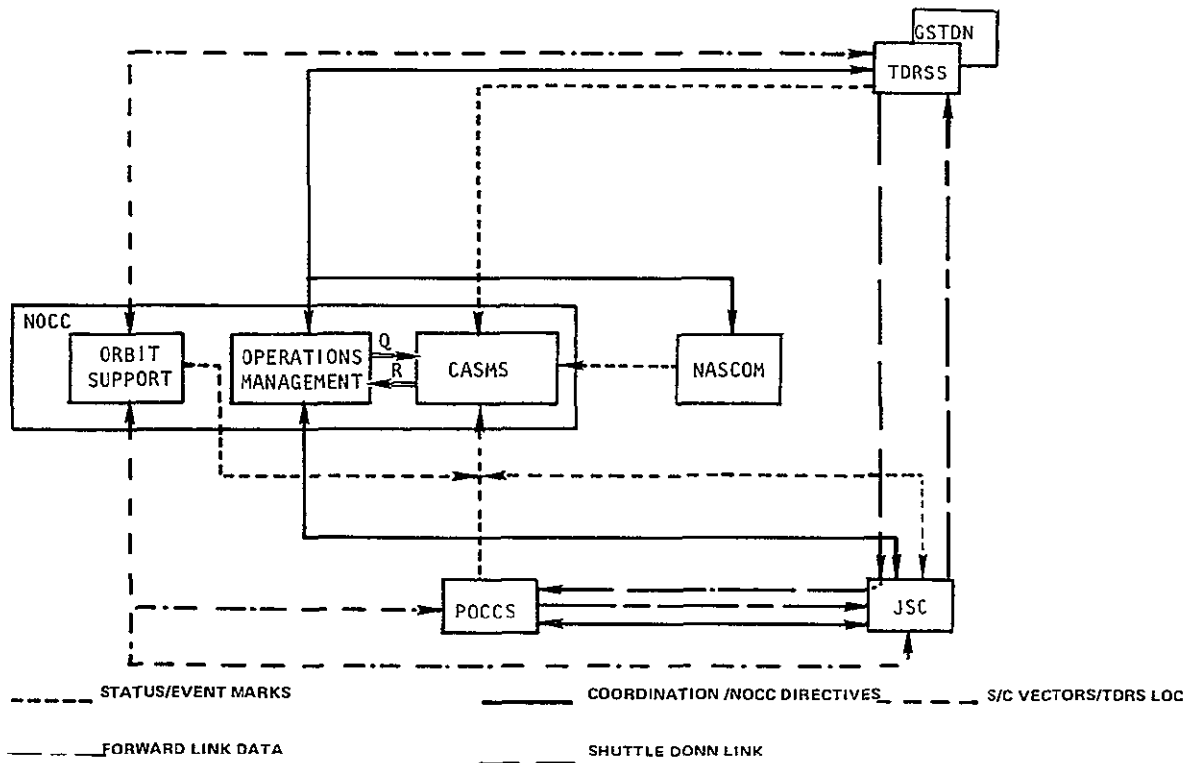


Figure D-20. Routine Service With Shuttle Information Flow (Decentralized Control)

APPENDIX E
REAL TIME DATA QUALITY ESTIMATES
IN THE TDRSS ERA

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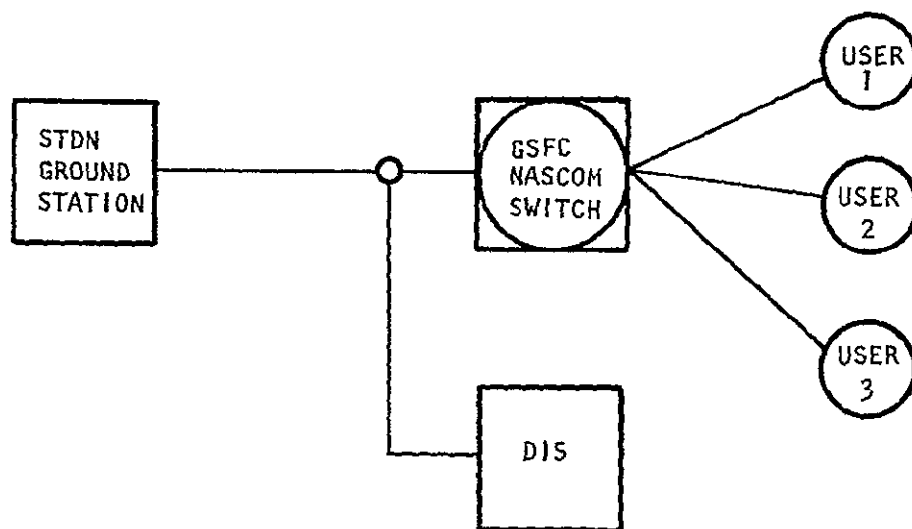
APPENDIX E
REAL TIME DATA QUALITY ESTIMATES IN THE TDRSS ERA

A. INTRODUCTION

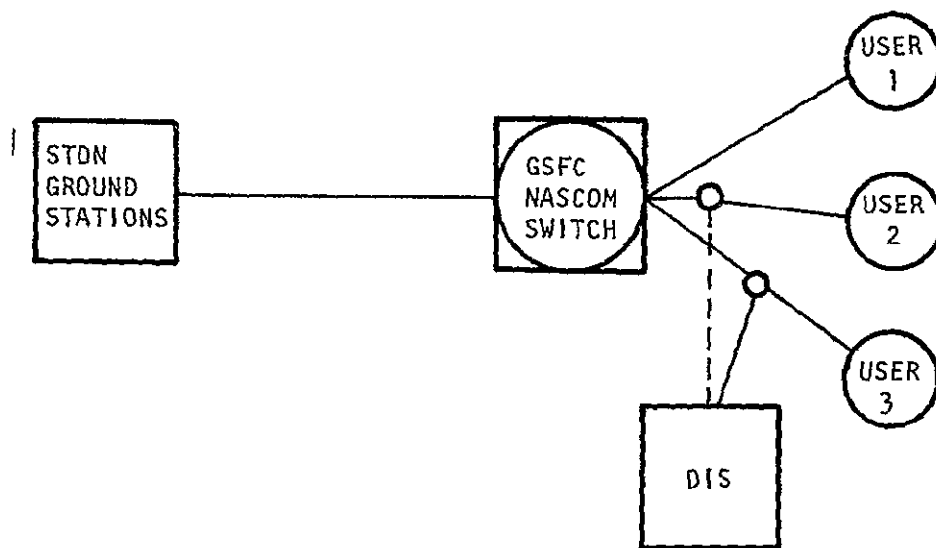
The STDN in the TDRSS era will provide a data communications service to users as a part of its overall responsibility of supporting manned and unmanned space activities. Data quality monitoring can provide the Network Operations Control Center (NOCC) the capability of insuring a specified level of quality for the data communications service. Several methods for data quality monitoring exist. One alternative of data quality monitoring is to actually inspect parameter values contained in a spacecraft return link data stream. A second alternative is to monitor data communications channel performance parameters instead of the actual data. In the following sections of this appendix each alternative is discussed. An evaluation of these alternatives is provided at the conclusion of this appendix.

B. DATA INSPECTION

Data inspection is a process whereby known spacecraft parameters are extracted from a return link data stream. The digitized values of these parameters are converted to alphanumeric form and presented on a visual display for review by a data quality observer. Several alternative points for sampling the user spacecraft data stream exist. Figure E-1 suggests two representative alternatives. The first (E-1a) routes the 1.5Mb and/or 56Kb data channel information to the Data Inspection System (DIS). The DIS then demultiplexes the data information into individual user data streams, searches the desired stream or streams for the parameter of interest, translates the digital representation of the parameter value to alphanumeric form and finally displays it for review by the data quality observer in the NOCC. The second alternative provides the NASCOM demultiplexed user data stream (or streams) to the DIS. The DIS then performs similar functions as those described above.



(a) INTERFACE PRIOR TO GSFC NASCOM SWITCH



(b) INTERFACE AFTER GSFC NASCOM SWITCH

Figure E-1. Representative Data Inspection System Interface Points

For the remainder of this discussion, the second alternative will be assumed. This assumption is made to avoid the duplications of NASCOM switch functions in DIS. Since the demultiplex hardware and software will exist at GSFC, inclusion of these functions in the DIS is seen as incurring an unneeded expense.

1 Error Characterization

The granularity of the data quality estimate that can be obtained with the data inspection procedure is directly related to the ability to characterize the errors introduced into the digital telecommunications channels. In describing and quantifying such errors, problems in finding indicators for the significant complications can be encountered. Some error sources can induce random bit errors into a digital transmission. Other sources can induce degradation ranging from short bursts of errors to total channel outages. As noted in Reference 13, digital errors on telephone circuits tend to be bunched together but how the occurrence of such errors can be correlated with easily observable phenomena is difficult to determine. Similarly, in Reference 14, data on the probability that "n" bit errors occur in a block of "n" consecutive bits is seen to be quite diverse. It is obvious that the actual error data on telephone channels cannot be described by just one process but instead requires the mixture of several such processes for satisfactory description.

This channel characterization problem can be simplified, however, if one requires only "gross" indicators of channel or link performance. By the term "gross," the following is suggested:

If a parameter is allowed to assume a range of values from X to Y, it is only important to know that the value read is equal to or greater than X but less than or equal to Y.

For example, if spacecraft battery voltage is known to lie in a tolerance of 1 to 5 volts then a reading of less than 1 or more than 5 may indicate a problem. Whether the battery voltage transmitted was 2 volts and the received value is 2.5 volts is not of concern. The importance of this definition cannot be overemphasized since it is fundamental to the sampling technique

one chooses. If the above concept of "gross" is accepted, it can then be implied that the channel is suffering a significant burst error condition or catastrophic outage condition.

In the absence of any specific information concerning the mechanisms by which errors are induced on STDN data channels to be used in the TDRSS era, certain assumptions must be made. Experience with modern data communications networks have shown that the exponential distribution is a gross estimate for times between failures on a channel. That is, the probability P that the channel will fail between the present time and time T is given by

$$P = \int_0^T \lambda e^{-\lambda t} dt = 1 - e^{-\lambda T}$$

When two channels having exponential failure rates are connected in series, and the exponential parameters associated with each channel are given by λ_1 and λ_2 , respectively, the resulting composite channel has its failure rate exponentially distributed with parameter $\lambda_1 + \lambda_2$. More generally, if "n" exponential circuits with parameters $\lambda_1, \lambda_2, \dots, \lambda_n$ are connected in series, then the resulting composite circuit is exponential with parameter $\lambda_1 + \lambda_2 + \dots + \lambda_n$.

Suppose a data stream, D , may flow through one of two parallel channels C_1 and C_2 , going through C_1 with probability P_1 and through C_2 with probability P_2 . If C_1 and C_2 have exponential failure rates with parameters λ_1 and λ_2 respectively, then the time between failures witnessed by sampling D has the probability density function

$$S(t) = P_1 \lambda_1 e^{-\lambda_1 t} + P_2 \lambda_2 e^{-\lambda_2 t}.$$

However, if both C_1 and C_2 have the same failure rate (i.e., $\lambda_1 = \lambda_2 = \lambda$) then the above expression reduces to

$$S(t) = \lambda e^{-\lambda t}$$

For the system under consideration (Figure E-2) the 1.5Mb channels linking the TDRSS ground station and GSFC are assumed to have the same failure characteristic, designated λ_4 . Similarly, the 56Kb links from the GSTDN ground tracking stations are assumed to have the same failure rate, λ_5 .

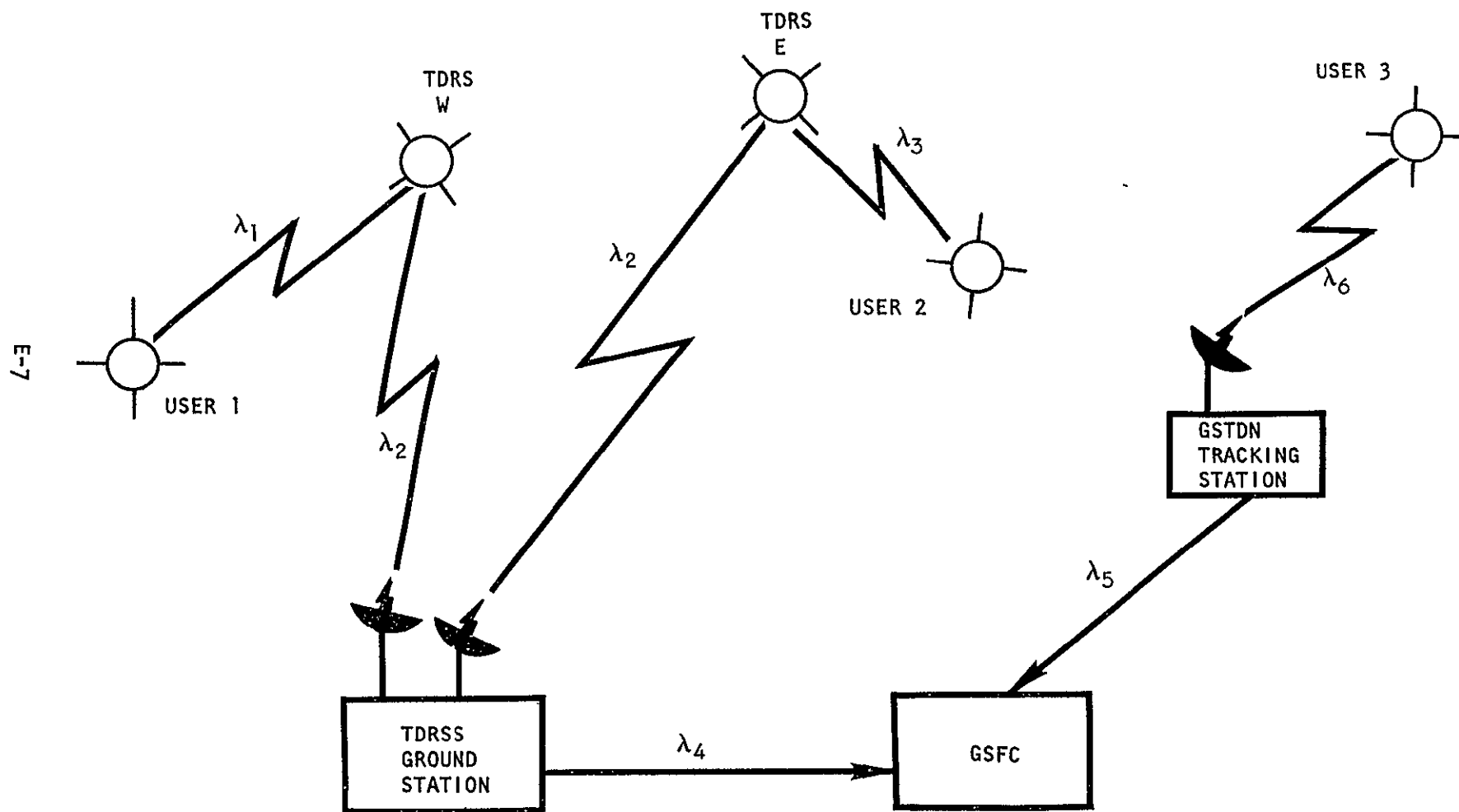


Figure E-2. TDRSS Era STDN Configuration

For analysis purposes, then, the channels between user satellites and the GSFC may be considered serial combinations (λ_T) of channels with parameters $\lambda_1, \dots, \lambda_n$. It must be kept in mind that potentially more than one path exists from the ground stations (TDRSS & GSTDN) to GSFC. Similarly λ_T will assume different values when user satellite to TDRSS or user satellite to GSTDN station links are different (λ_1, λ_3 and λ_6 in Figure E-2).

2. Detecting Failures

Consider a data stream from a user satellite S (user 1 in Figure E-2, for example). To detect failures we wish to find a sampling interval, H_s , which provides "satisfactory" identification of failure occurrences. Suppose it is desired to find a sampling interval such that the probability of the data channel not failing within the interval H_s is greater than or equal to Q . Alternatively, Q is the probability that the channel did not fail since the last sample. It can be shown that H_s satisfies the formula,

$$H_s = -\ln(Q) \cdot \frac{1}{\lambda_T}$$

In the example of user satellite 1 (Figure D-2), $\lambda_T = \lambda_1 + \lambda_2 + \lambda_4$.

The above formula indicates that H_s is proportional to the mean time between failures of the composite channel ($1/\lambda_T$), the factor of proportionality being $-\ln(Q)$. Table E-1 provides representative values of H_s for various λ_T 's and Q 's. From Table E-1, if the failure rate, $1/\lambda_T$, is once per day (24 hours), a sampling interval of approximately 19 hours provides an .80 probability that the channel will have failed since the last sample ($Q = .2$). If this system is used for determining H_s , it can be shown that the expected time, E_s , from actual failure until detection of the failure is given by,

$$E_s = \frac{1}{\lambda_T} \left(-1 - \frac{\ln Q}{1-Q} \right)$$

Values of the factor of proportionality, $\left(-1 - \frac{\ln Q}{1-Q} \right)$, as a function of Q , are given in Table E-2

The sample interval requirement can be looked at from a different viewpoint. Suppose it is desired to find failures within some time τ after

TABLE E -1 REPRESENTATIVE VALUES OF
SAMPLING INTERVAL H_s

$1/\lambda_T$ (HRS)	Q			
	.5	.6	.7	.8
50	34.7	25.5	17.8	11.2
100	69.3	51.1	35.7	27.3
150	104	76.6	53.5	33.5
500	346.6	255.4	178.3	111.6

TABLE E -2 PROPORTIONALITY FACTOR VALUES

Q	$(-1 - \frac{\ln Q}{1-Q})$
.5	.39
.6	.28
.7	.19
.8	.12

they have occurred. For a user satellite, S , let H_S^* be the interval for sampling the data stream from S and let it have the property that any failure will be detected within time τ with probability greater than or equal to Q^* . It should be clear that if $Q^* = 1$ then H_S^* must be τ , otherwise H_S^* can be bigger than τ . It can be shown that the formula for H_S^* is given by

$$H_S^* = \frac{1}{\lambda_T} - \ln \left[\frac{Q^*}{\exp(\gamma \lambda_T) + (Q^* - 1)} \right]$$

Table E-3 provides sample values for H_S^* when Q^* is held fixed at 7 , and λ_T and τ are variables. Table E-4 gives similar values where τ is fixed at 10 hours and λ_T and Q^* are variables. Notice that the entries in any column of either table are nearly the same. This demonstrates an interesting feature of this approach to sampling. If it is desired to detect failures within time τ with probability Q^* , then sample interval H_S^* is largely independent of $1/\lambda_T$. Thus, the sample interval is not highly dependent on the original distribution of failures. In particular, all satellite data streams in multisatellite systems could be sampled with the same frequency.

The above sampling techniques provide a data quality observer the capability to detect major channel outages; i.e., those caused by equipment failures or significant natural or man-made descriptions of the data channel. Without specific knowledge of the characteristics of the degradation sources or the channel of interest, sampling techniques to detect other data quality degradations are extremely difficult to specify with reasonable degrees of accuracy.

C. PERFORMANCE PARAMETER MONITORING

Performance parameter monitoring is the process whereby fundamental communication channel characteristics are monitored and the values compared to predefined thresholds.

Many organizations provide data communications services to users. These organizations include AT&T, COMSAT, Western Union and DATRAN. Specialized

TABLE E-3 VALUES OF H_S^* IN HOURS WHEN $Q^* = .7$.

$1/\lambda_T$ (HRS)	τ (HRS)			
	1	10	100	200
50	1.42	13.74	114.76	217.56
100	1.43	14.00	123.97	237.52
150	1.43	14.09	128.41	241.14
500	1.43	14.23	137.41	266.08

TABLE E-4 VALUES OF H_S^* IN HOURS WHEN $\tau = 10$ HOURS

$1/\lambda_T$ (HRS)	Q^*			
	.5	.6	.7	.8
50	18.33	15.70	13.74	12.22
100	19.09	16.15	14.00	12.35
150	19.37	16.31	14.09	12.40
500	19.80	16.56	14.23	12.47

networks also exist for providing data communications services (e.g., ARPANET, ALOHA, etc.). These organizations and services have a requirement to ensure the quality of service provided as well as detecting, isolating and restoring degraded network elements. These organizations, for a wide range of reasons, do not sample user data to determine channel integrity. Some of these reasons are

- (1) The need for user-unique equipment to recover the actual data
- (2) The user's desire for privacy
- (3) The existence of off-the-shelf equipment to provide desired information in a timely manner, thus minimizing cost.

The methods utilized currently by the data communications industry to determine channel (data) quality are generically classed as channel parameter monitoring and include measurements of:

- (1) Channel tolerances (phase, frequency, amplitude)
- (2) Known bit pattern distortions
- (3) Pulse quality
- (4) Error detection code performance
- (5) Convolution decoder performance
- (6) S/N levels
- (7) Phase-Locked Loop (PLL) performance

The TDRSS performance specification (Reference 4) indicates that a significant number of performance parameters are being provided to the NOCC by TDRSS. These include

- (1) EIRP
- (2) Radiated carrier frequency
- (3) RF beam pointing
- (4) Polarization
- (5) Carrier lock indicator
- (6) BER status
- (7) Signal strength indication from ground carrier tracking receiver
- (8) Port ID

The above data provides the fundamental information to obtain estimates of TDRSS data quality for a wide range of confidence levels. A comparable set

of parameters from the GSTDN stations could similarly provide the foundation for GSTDN data quality estimates.

The approach suggested utilizes automated techniques within the NOCC to ensure that a man does not have to sit at a console and continuously monitor the above data. Since the prime motivation of data sampling at the NOCC is to obtain indications of degraded data quality, the parameter processing system in the NOCC could be designed to register channel status changes which exceed predefined thresholds.

Consider the parameter identified as "BER Status" above and in Reference 4. For convolutionally encoded links, the performance of the decoder could provide indicators of BER status. Alternatively, TDRSS, in parallel with user data transmissions, could be transmitting a known bit pattern between the TDRS and TDRSS ground station and monitoring its received error rate. Either method would allow the TDRSS contractor to supply the BER Status information to NASA as required in the performance specification. This parameter alone could provide gross indications of TDRSS channel performance, i e., data quality.

Similarly, NASCOM applies an error detecting poly-code to all data blocks transmitted from ground sites to users. When errors are detected in a block, an error status flag is set indicating a potential block data error.

The above data provides the basis for a very flexible data quality estimating system. A generic functional flow for such a system is shown in Figure E-3. A representative printout of this type of system (in use today in government applications) is shown in Figure E-4. The inherent flexibility in this type of system resides in the ability of the channel (data) quality observer to determine the sensitivity of the observations(i.e., input parameter threshold values). The GREEN, AMBER and RED operating regions for each parameter are selected based on pre-established thresholds. Channel performance is then determined by the mini-processor with a center GREEN (most desirable region) value as the point of reference. Values for high and low AMBER thresholds (marginal circuits) and high and low RED thresholds (unusable circuits) are then set by the NOCC operator. Certain parameters,

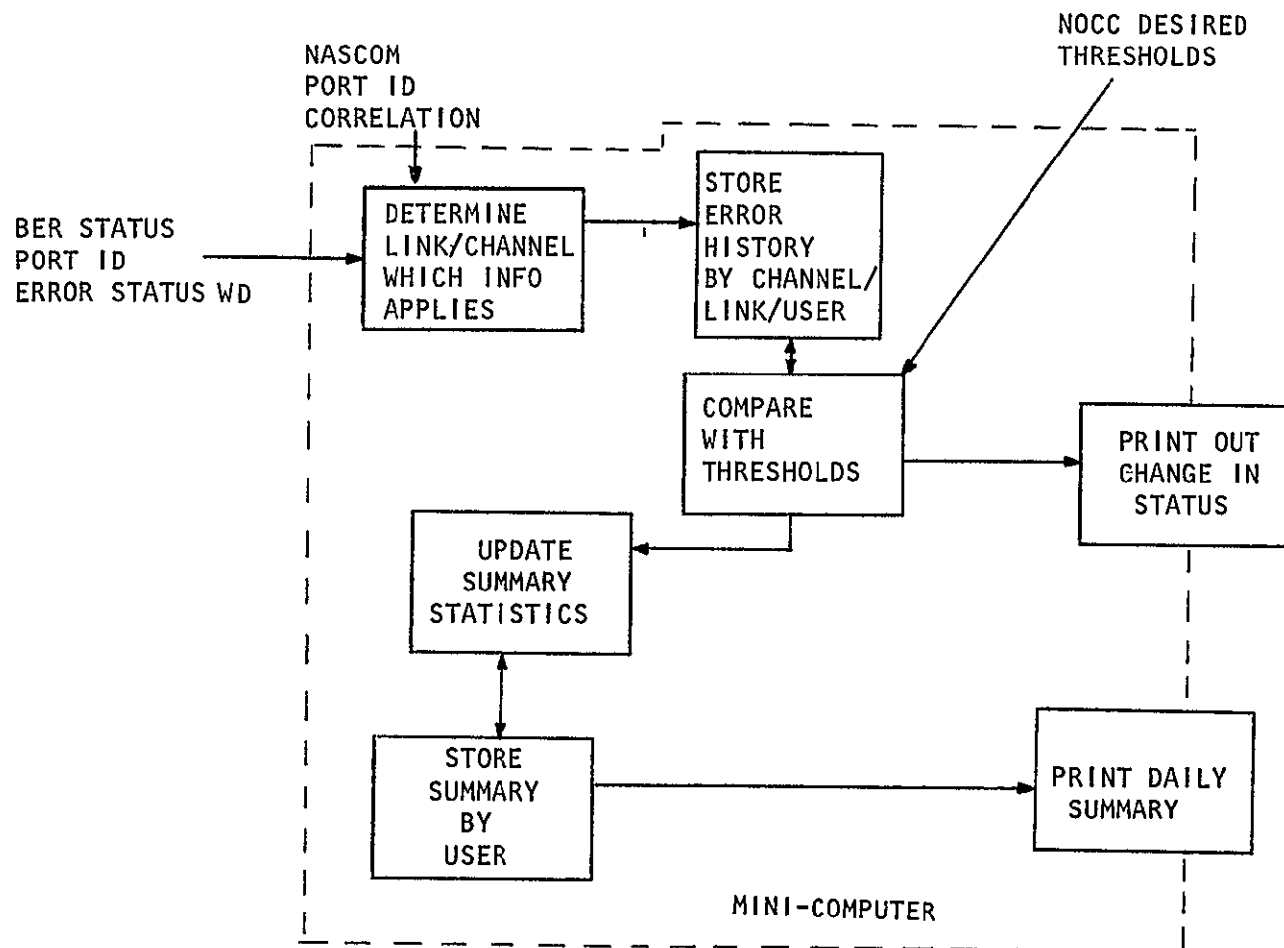


Figure E-3. Generic Functional Flow for a Data Quality Estimating System

THE BDM CORPORATION

AH ** 118/2347 070T
AH ** WN -48.6

RH ** 118/2347 070R
RH ** WN -43.2

G -T 118/2351 119R
G -T WN -70.9

AH ** 118/2353 130T
AH ** WN -48.1

AH ** 118/2354 148T
AH ** WN -51.2

AH ** 118/2354 148R
AH ** WN -51.1

AH ** 118/2354 149T
AH ** WN -51.2

AH ** 118/2355 149R
AH ** WN -51.0

AH ** 118/2355 156T
AH ** WN -51.0

AH ** 118/2356 156R
AH ** WN -50.9

AH ** 118/2356 157T
AH ** WN -50.7

AH ** 118/2356 157R
AH ** WN -51.1

Figure E-4. Representative Printout of a Channel Quality Monitoring System

monitored on a continuous basis, can be used to establish circuit quality trends. If gross estimates are desired, the thresholds are set to detect very large parameter value excursions from the norm (i.e., RED regions). For example, the first line in Figure E-4 indicates that on Julian date 118 (28 April) at 2347 hours Zulu, the weighted noise level (WN) exceeded the threshold for "Amber" (AH). The measured value of the wideband noise at the time of threshold crossing was 48.6dB. In this example, the observer desired to know when the data channel was entering a possible degradation situation, thus the use of "amber" thresholds. Channel quality is not bad but it is not within desired tolerances. Continuation of the amber condition for prolonged lengths of time could have indicated to the observer that circuit adjustments were necessary.

If an observer were only interested in very significant changes in channel quality, "Red" and "Green" thresholds may be the only values defined. The second circuit, 70R, identified in Figure E-4, entered a "Red" (RH) condition at the same time 70T entered the "Amber" state. Notice that the wideband noise power on this channel is more than double that on 70T. Directly following this example in Figure E-4, circuit 119R has returned to the "Green" state, representing a status change from a previous "Amber" or "Red."

In summary, the above system could provide a data quality observer the capability of detecting data channel corruptions to the level desired, using information which will be available. Additionally, this information provides a technical support team within the NOCC the basis for problem isolation and system restoration.

D. APPROACH EVALUATION

Review of the Network Operations Support Plans for the Atmospheric Explorer-E, Earth Resources Technology Satellite and Orbiting Solar Observatory missions (References 15, 16 and 17 respectively) indicate that reference parameters such as battery voltages, bus currents, etc. can not be expected to appear at consistent places in the various spacecraft telemetry streams. Therefore a duplication of user hardware and software will be required to

extract and interpret the desired parameter. It would be expected that future telemetry stream construction would be driven by user requirements and these would not be expected to be consistent among satellite system

Without a detailed specification of the corruptive influences on the channel being monitored, data inspection is limited to detecting only the most severe outages. Reference 14 provides data relating to extensive tests conducted by AT&T to characterize channel degradations. As a result, the telephone network could be represented by a combination of renewal type channels by specifying about a dozen parameters. However, this specification is only valid for the block sizes which are significantly different from those planned for use by NASCOM in the TDRSS era. Unless extensive testing is undertaken to characterize the NASCOM network in the TDRSS era, corollary information relating to channel performance will be required to determine whether a channel outage is actually in process. This additional information will also be required for malfunction isolation. Reference 4 indicates that a substantial set of this information will be available at the NOCC. If this is the case, the data inspection approach would require additional data to perform a function which could be accomplished with existing data. Additionally it presents a distinct disadvantage of being limited in the quality and quantity of information provided to an observer. Assuming that the TDRSS user links are of a reliability at least nearly equivalent to existing satellite communications relay links, a data quality observer would spend much of his time monitoring "good" performance. Human factors data shows that unless the motivation is extremely high, an individual tends to ignore things which do not add to the total information base, i.e., things are assumed to be the way they most often appear. Section C suggested a system which could use existing information in an extremely flexible manner. In fact, estimates of data quality are potentially obtainable for a wide range of granularities. Additionally the necessary and sufficient set of information for malfunction identification and isolation is utilized to extract data quality estimates, thus minimizing information processing at the NOCC. It was also suggested that the performance parameters monitoring system be designed to identify "bad" conditions thus removing routine

task of reviewing large amounts of "good" data. Summary reports are utilized to extract performance statistics for operations during those periods in which malfunctions do not occur. In conclusion it should be noted that performance parameter monitoring is a data communications industry standard technique. Years of experience accumulated by a wide range of data communications companies and organizations have established confidence in this approach. For these reasons, performance parameter monitoring has been selected as the preferred technique in obtaining real-time estimates of STDN data quality

APPENDIX F
STDN LOADING DATA

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APPENDIX F
STDN LOADING DATA

The graphs in this appendix were accumulated from the Mission Model (Reference 2) and data assembled for the Phase I report (Reference 1). Figure F-1, GSTDN DEMAND, represents the range of possible loading on GSTDN until 1982. The graph marked MINIMUM APPROVED reflects commitments already made for support of spacecraft either presently in orbit or slated for launch. The MAXIMUM APPROVED curve which continues into the ESTIMATED PROBABLE segment after 1980 represents the aggregate desired level of support until 1980 and the estimated likely level thereafter. After 1980, the MAXIMUM TOTAL curve indicates a worst case for demand on GSTDN. The RESOURCES curve represents total available antenna time in each quarter. The dotted downward slope of this curve in the period from mid-1980 to mid-1981 is associated with the phaseout of ground stations planned when TDRSS becomes operational.

Figure F-2, TDRSS DEMAND, represents estimates of aggregate demand for TDRSS SA and MA support along with a total of the two.

Finally Figure F-3 contrasts expected demand for TDRSS SA support with available SA-antenna hours, both without the limitation of two operational Shuttle spacecraft and with one SA antenna dedicated to each shuttle at all times

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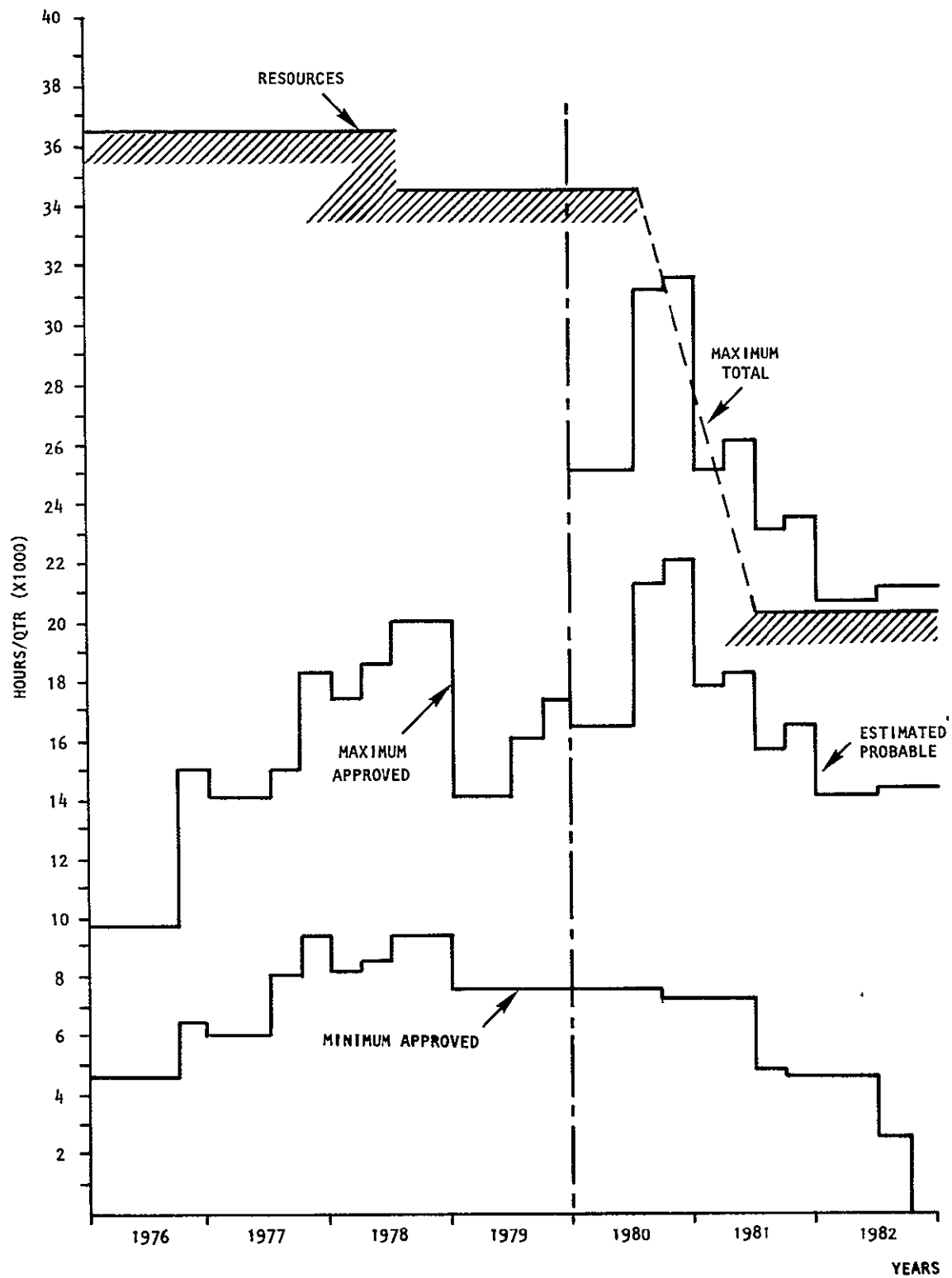


Figure F-1. GSTDN Demand
F-4

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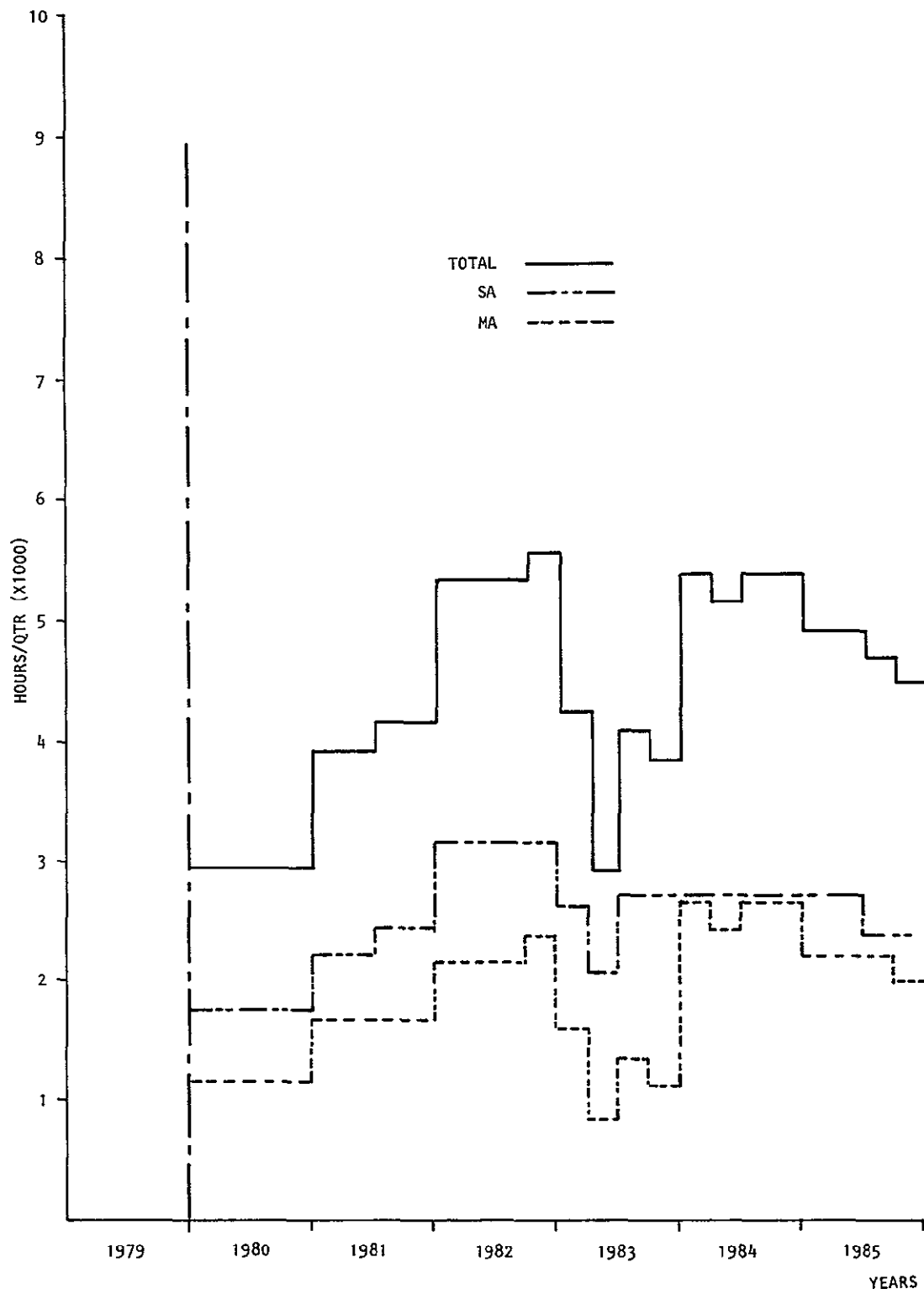


Figure F-2. TDRSS Demand

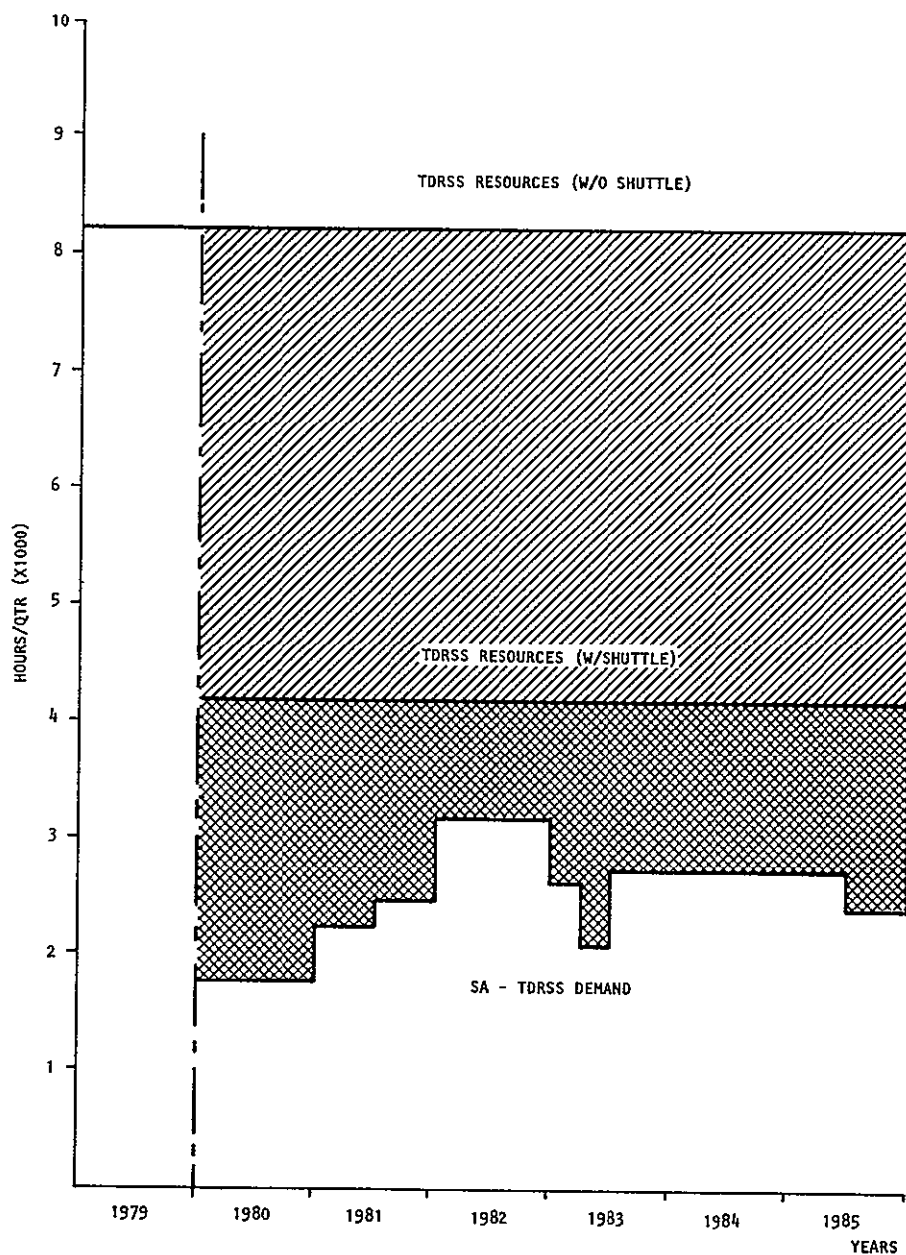


Figure F-3. TDRSS Demand, with the Shuttle

APPENDIX G
SPECIALIZED HUMAN FACTORS PRIMER

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APPENDIX G
SPECIALIZED HUMAN FACTORS PRIMER

A INTRODUCTION

Human factors analysis, especially in the TDRSS era NOCC context, or any context, is a highly complex and interactive problem. Figure G-1 indicates the factors which bear on such an analysis and their relative interactions. Solid lines indicate strong interactions, dotted lines weak interactions. Many of the factors show direct control by management personnel. For example, financial reward may be governed by a set of "established" rules. However, working conditions is an area that usually provides high visibility to both employee and employer. Changes in this area seldom go unnoticed. Additionally, it is the area in which management generally has the greatest impact. Therefore, this primer focuses on the area of working conditions.

It is the intent of this appendix to generate an awareness of the salient human factors aspects which should be considered as the NOCC evolves into TDRSS era operations. As such, it is important to note that it does not provide specific answers to identified areas of concern but rather provides guidelines and methodologies for defining and implementing fixes if operation in the current set of conditions is determined to be objectionable.

Following this introduction, a discussion of human factors data lays the foundation for the workload and job setting subjects discussed in Section C. Knowledge of the types and kinds of data available in human factors testing will support overall analyses and define analysis bounds. Section C treats the specialized subject areas. These subjects are discussed in a generalized fashion, and hence specific solutions to problems in these areas are not identified. The fundamental reason for this is that the level of analysis required to provide specific answers in these areas is significantly greater than the levels of analysis of the remaining subject areas in the Phase II effort. However, direction is provided to salient studies and references dealing with the subject matter in Section C. A bibliography and referral matrix (Section D) include the human factors primer.

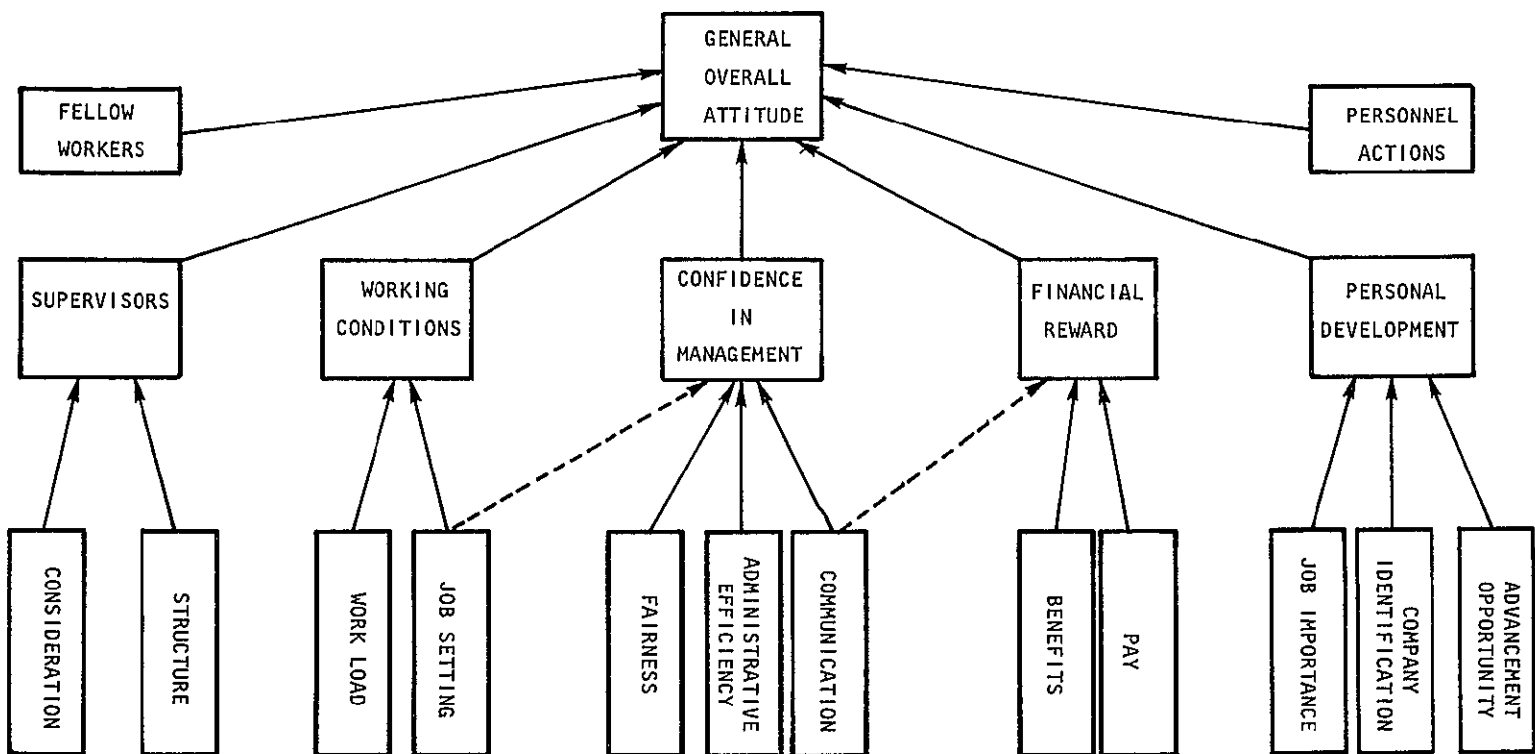


Figure G-1. Factors Bearing on Human Factors Analysis

B. HUMAN FACTORS DATA METHODOLOGY AND APPROACH

An accepted methodology for the collection and analysis of human factors data includes the determination of what/who is to be assessed, how the assessment will be conducted, and in what context the assessment will take place. Figure G-2 summarizes this methodology and shows the components of each major step. .

The first five steps shown in the figure have key significance in that they are conducted before data collection, often a costly endeavor, is initiated. Briefly, the first step in the methodology involves defining the type of behavior one is attempting to describe or predict. That is, determine if the objective of the analysis is to describe or predict individual, group, or system performance (or interrelationships of these performances). This first step literally "bounds" the assessment to be undertaken and is obviously influenced by three major parameters while recognizing the existence of a possible man-machine interface. This interface will be discussed in a subsequent section.

The three parameters are personnel, functions or tasks, and environment. The personnel parameter considers physical and psychological characteristics along with "number" and background. Physical characteristics assessed would include age, sex, race, and physiological and anthropometric considerations. Measurement of these characteristics are beneficial in determining limitations of human performance. Similarly, psychological characteristics (aptitude, skill and personality) are beneficial in describing how and why humans perform. The "number" factor, moreover, assesses the influences of the personnel parameter on the amount and type of training and experience the individual (or group) has or will obtain. As with the psychological characteristics, these are beneficial in determining how well humans perform. The second parameter assesses the type of task(s) to be performed, the characteristics of these tasks and the behaviors required to perform them. The personnel and task parameters are influenced by the situational environment in which they exist--hence, the need for an assessment of the "environment." The physical location would be determined, as well as evaluations of

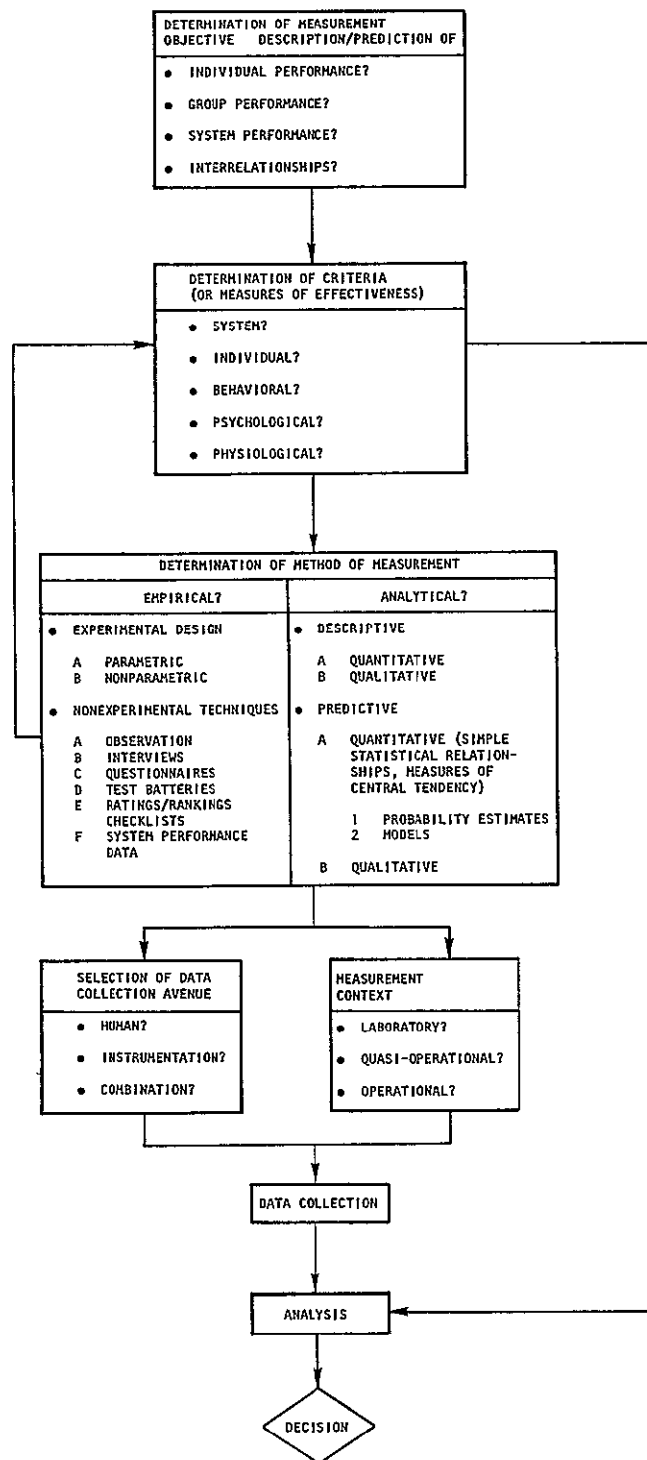


Figure G-2. Modified Methodology for Human Factors Analysis

the influences of temperature, noise, lighting, acceleration, vibration, and atmosphere.

Having made a decision on what the objective of the assessment is to be, the second step is to establish criteria which would state the performance requirement for the objective to be successfully accomplished. Consideration must then be given to determining the method of measurement, the third step in the methodology. At this point, the use of experimental designs, questionnaires, interviews, models, etc. would be determined. Steps four and five are directly related to data collection. After deciding if the data will be collected by using human resources, instrumentation, or both, consideration must be given to the context in which the measurement is to be made. That is, is the assessment to be conducted in an operational setting, or a laboratory, etc. It must be emphasized that these five steps are fluid and, therefore, strongly interact with each other. A change in the approach to the method of measurement, for example, could well affect measurement context. For cost effectiveness and other reasons, these changes should be determined before data collection is initiated, step six in the methodology. After the data has been reduced and subsequently analyzed using both the criteria decided upon in step two, and applicable methods of measurement decided upon in step three, the decision which precipitated the need for the human factors assessment can be made. A detailed discussion of this methodology can be found in Meister, 1971 (Reference 1)

It is important to recognize that this methodology forms a checklist for determining when the numerous considerations in a human factors assessment should be discussed, evaluated, and otherwise employed to arrive at a situationally dependent decision. Admittedly, this discussion has not mentioned the use of applicable statistics which are often employed in psychophysical and psychometric portions of human factors assessments. Discussions of these techniques can be found in Kirk and Guilford (References 2 and 3).

C. TOPICS OF INTEREST

This primer has taken key aspects of the personnel, function, and environmental parameters cited earlier and addressed them as foundations for a much larger and structured assessment, an assessment that would pursue the methodology stated above. The aspects considered are the man-machine interface, illumination, temperature, noise, hours and shifts, fatigue, selection and training, and human relations.

1. Man-Machine Interface

The man-machine interface is a topic which is often addressed and less often understood. It is a consideration of great importance which has been addressed in volumes of literature from many perspectives. Certain generalizations have been identified which can be of benefit to NASA and it is these generalizations which have been presented to assist NASA officials in their approach to a human factors analysis. Humans and machines have definite attributes which must be taken into account when allocating tasks and functions to each. Generally, as Jordan said, "men are flexible but cannot be depended upon to perform in a consistent manner, whereas machines can be depended upon to perform consistently but have no flexibility whatsoever." (Reference 4)

Generalizations about the relative capabilities of human beings and of machine components are drawn from various sources and have been depicted in Figure G-3.

Given the attributes of man and machine, how does one draw the interface between them? In practice, this question is answered by allocating tasks or portions of tasks to each. No matter how carefully control tasks are apportioned between man and machine, the match will never be perfect.

The characteristics listed above are generalizations, guidelines made under the assumption that all other conditions are ideal. There are circumstances, extreme environmental conditions for instance, in which it would be inappropriate to apply these guidelines as dictates of a general superiority of either men or machines. Furthermore, due to technological

MACHINE

- SENSE STIMULI OUTSIDE OF MANS NORMAL RANGE (EG, X-RAYS)
- MONITOR FOR PRESPECIFIED EVENTS OR PATTERNS
- STORE LARGE QUANTITIES OF CODED DATA
- MAKE RAPID CONSISTENT RESPONSES TO INPUT SIGNALS
- PERFORM REPETITIVE ACTIVITIES RELIABLY
- COUNT OR MEASURE PHYSICAL QUANTITIES
- MAINTAIN EFFICIENT OPERATIONS UNDER CONDITIONS OF HEAVY LOAD
- MAINTAIN EFFICIENT OPERATIONS UNDER DISTRACTIONS
- HIGH POWER REQUIREMENT
- COST AND TIME LIMITED SUPPLY BUT EXPENDABLE AND NO PERSONAL PROBLEMS
- EXTENSIVE MAINTENANCE REQUIREMENT FOR COMPLEX MACHINE

MAN

- SENSE LOW LEVEL VISUAL, AUDITORY, TACTILE STIMULI
- RECOGNIZE PATTERNS OF COMPLEX STIMULI WHICH VARY WITH SITUATION (E G SPEECH SOUNDS)
- STORE PRINCIPLES AND STRATEGIES
- DRAW UPON VARIED EXPERIENCE IN MAKING DECISIONS
- REASON INDUCTIVELY, GENERALIZING FROM OBSERVATIONS
- MAKE SUBJECTIVE ESTIMATES AND EVALUATIONS
- CONCENTRATE ON IMPORTANT ACTIVITIES WHEN OVERLOAD CONDITIONS REQUIRE
- ADAPT PHYSICAL RESPONSE TO VARYING OPERATIONAL REQUIREMENTS
- LOW POWER REQUIREMENTS
- IN GOOD SUPPLY, BUT NONEXPENDABLE
- LOW MAINTENANCE REQUIREMENT

Figure G-3. Man-Machine Trade-Offs

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advances in hardware and software and scientific research on human beings, the accepted view of human and machine capabilities in the various areas is subject to constant change. Economic considerations may also govern task allocation within a given system.

Finally, function allocation should also take social and related values into account. The process of allocation of functions to men versus machine components directly predetermines the role of human beings in systems and thereby raises important questions of a social, cultural, economic, and even political nature. The basic roles of human beings have a direct bearing upon such factors as job satisfaction, humans motivating the value systems of individuals and of the culture, etc. Preferably, the human work activities that are generated by a system should provide the opportunity for reasonable intrinsic satisfaction to those who perform them.

2. Illumination

Once again, there are a number of considerations which influence decisions relating to types and levels of work place illumination. Some of these considerations include the nature of the tasks which will be performed, the quantity and uniformity of the light which will be provided, and glare and reflections from work area surfaces and light sources.

The majority of literature available on the subject of illumination is directed toward the performance of detailed tasks requiring various levels of room brightness. The display operator is in a rather unique situation in this regard because his work task and equipment require special considerations. Three conflicting requirements must be satisfied. There must be enough general or ambient illumination for operators to walk around in the room, the light should not reach the face of the display (reduction in brightness contrast will occur), and indirect reflections from the face of the display should not reach the operator's eyes.

There are three types of artificial lighting systems. direct, indirect, diffuse. Direct lighting is most efficient, but often produces annoying and distracting contrasts, shadows, and glare. Indirect provides good uniform lighting without direct glare and deep shadows; however, it is inefficient and may produce specular glare if the ceilings and walls

are not suited for this lighting technique. Diffuse lighting is more efficient than indirect and less efficient than direct, and with fluorescent tubes and baffles, glare and shadows are almost eliminated. Specialized lighting systems have been designed for radar rooms, usually consisting of filter sets and goggles. The best known of these systems are a cross-polarization system, broad-band-blue system, sodium-minus-yellow system, and a mercury-minus-red system. Unfortunately, the three latter systems will not work with certain types of CRT displays. These systems also tend to distort color coding and may adversely affect the operators emotionally. The cross-polarization system does not transmit as much light as the three other systems and must be precisely positioned to properly polarize the room light.

Red illumination is often used for general lighting where dark adaptation is essential to the task being performed. It has many practical applications in work situations where it is necessary to preserve the dark adaptation of the rods in the retina. Electroluminescent lighting is commonly used for panels and displays. The advantages of this technique are uniform panel brightness and color.

Glare is a common problem of direct or inefficient lighting systems which markedly increases the visual acuity of the subject and causes eyestrain. Direct glare can be controlled by using direct lighting and using shields and hoods to keep the light from reaching the operator's eyes, or by using indirect lighting. Specular glare (reflection) can be reduced by using diffused light, and dull mat surfaces rather than polished ones. Figure G-4 provides standard lighting recommendations for special working conditions, and Figure G-5 identifies the light which can be saved through the use of color.

3. Temperature

The physiological impact of heat and cold stress results in work performance degradation in many activities, physical and mental. In view of the vast amount of work which has occurred in this area, and the effort of the study team to address those areas which particularly relate to NOCC conditions, this discussion will focus on relevant,

WORKING CONDITIONS		RECOMMENDATIONS	
CONDITION OF USE	LIGHTING TECHNIQUE	LUMINANCE OF MARKINGS (FT-L)	BRIGHTNESS ADJUSTMENT
INDICATOR READING, DARK ADAPTATION NECESSARY	RED FLOOD, INDIRECT, OR BOTH, WITH OPERATOR CHOICE	0.02-0.1	CONTINUOUS THROUGHOUT RANGE
INDICATOR READING, DARK ADAPTATION NOT NECESSARY BUT DESIRABLE	RED OR LOW-COLOR-TEMPERATURE WHITE FLOOD, INDIRECT OF BOTH, WITH OPERATOR CHOICE	0.02-1.0	CONTINUOUS THROUGHOUT RANGE
INDICATOR READING, DARK ADAPTATION NOT NECESSARY	WHITE FLOOD	1-20	FIXED OR CONTINUOUS
PANEL MONITORING, DARK ADAPTATION NECESSARY	RED EDGE LIGHTING, RED OR WHITE FLOOD, OR BOTH, WITH OPERATOR CHOICE	0.02-1.0	CONTINUOUS THROUGHOUT RANGE
PANEL MONITORING, DARK ADAPTATION NOT NECESSARY	WHITE FLOOD	10-20	FIXED OR CONTINUOUS
INDICATOR READING OR PANEL MONITORING WITH POSSIBLE EXPOSURE TO BRIGHT FLASHES	WHITE FLOOD	10-20	FIXED
INDICATOR READING OR PANEL MONITORING AT VERY HIGH ALTITUDE AND RESTRICTED DAYLIGHT	WHITE FLOOD	10-20	FIXED
CHART READING, DARK ADAPTATION NECESSARY	RED OR WHITE FLOOD, WITH OPERATOR CHOICE	0.1-1.0 (ON WHITE PORTIONS OF CHART)	CONTINUOUS THROUGHOUT RANGE
CHART READING, DARK ADAPTATION NOT NECESSARY	WHITE FLOOD	5-20	FIXED OR CONTINUOUS

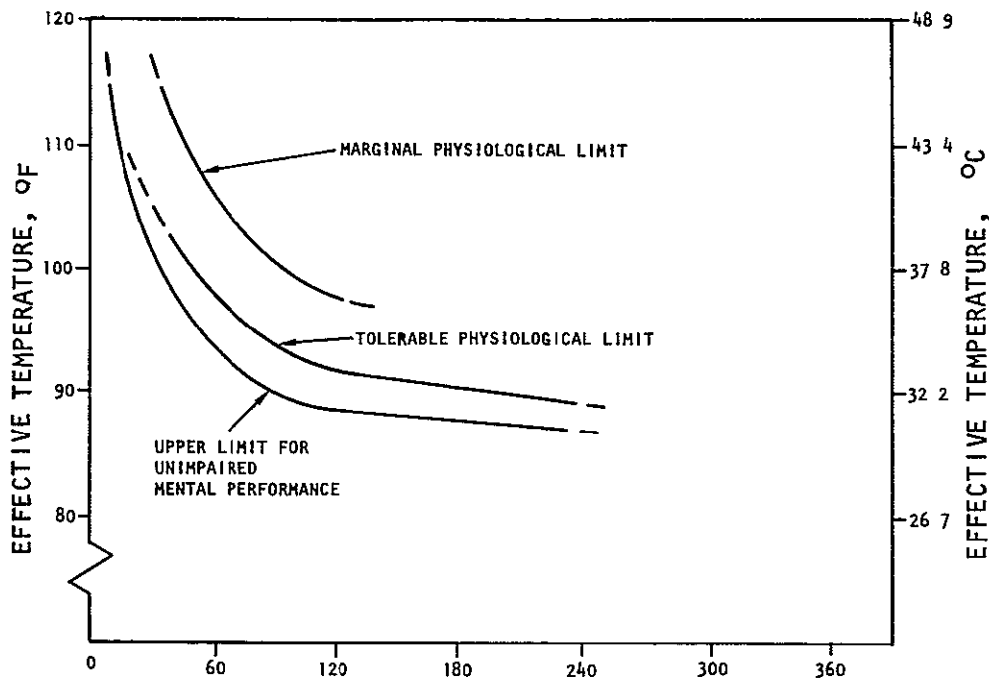
Figure G-4. Recommendations for Indicator, Panel, and Chart Lighting

CEILING		WALLS		FLOOR		FURNITURE		UTILIZATION COEFFICIENT, %
COLOR	RF*	COLOR	RF	COLOR	RF	COLOR	RF	
CREAM	65	WHITE AND GRAY	40	DARK RED	12	DARK OAK	20	29
CREAM	85	WHITE AND GRAY	40	DARK RED	12	DARK OAK	20	33
CREAM	85	GREEN	72	DARK RED	12	DARK OAK	20	45
CREAM	85	GREEN	72	WHITE	85	DARK OAK	20	56
CREAM	85	GREEN	72	WHITE	85	BLOND	50	57
CREAM	85	GREEN	72	WHITE AND RUSSET	70	BLOND	50	55

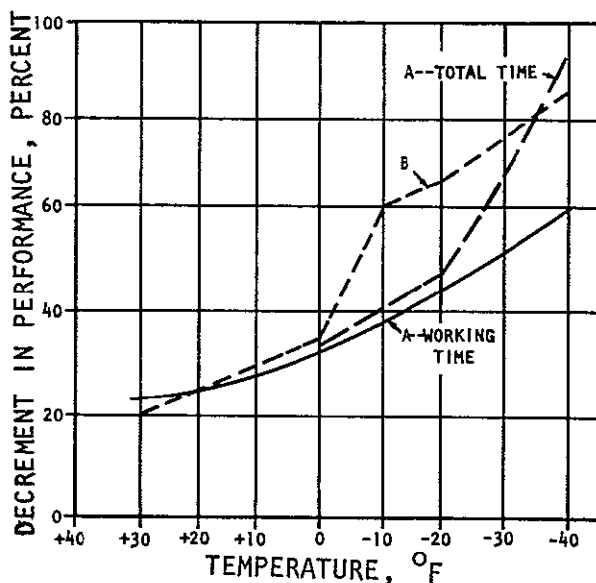
*RF = REFLECTANCE FACTOR (PERCENTAGE OF LIGHT REFLECTED).

SOURCE: A.A. BRAINARD AND R.A. MASSEY, SALVAGING WASTE LIGHT FOR VICTORY, EDISON
ELECTRIC INSTITUTE BULLETIME, 1942, VOL. 10.

Figure G-5 Effect on Illumination of Various Ceiling, Wall, and Furniture Combinations



Tentative upper limit of effective temperature for unimpaired mental performance as related to exposure time; data are based on an analysis of 15 studies. Comparative curves of tolerable and marginal physiological limits are also given.



- A Results of performance of task which required brush assembly breakdown: total time includes working time and warming-up time.
- B Operational efficiency of flying personnel in an open cockpit.

Percentage of decrement in performance on two tasks under different temperature conditions.

Figure B-6. The Effects of Heat and Cold on Work Performance

applicable information which identifies the relationship of heat and cold stress to performance in mental activities.

The effects of heat on an individual's performance on mental activities are closely related to other influencing factors: the type and duration of the task being performed, the individual's training, and the degree of acclimatization of the individual. Generally, an individual's performance of light work will begin to deteriorate at about 86° to 88°F. The four factors which affect the heat exchange process are temperature, humidity, air circulation, and the temperature of other objects in the environment. For example, heat dissipation is restricted to evaporation in a situation where air and wall temperatures are high because convection and radiation cannot effectively impact the process.

There are a number of methods in use for measuring environmental factors. The effective temperature (defined by the ASHRAE Handbook of Fundamentals) provides a single value for the effect of temperature, humidity and air circulation on the human body. The operative temperature provides a scale which also accounts for air and wall temperature but not humidity. In one of the studies performance degradation occurred only after an extended period of time, 1 1/2 hours in this case (Reference 6). These results imply that for a short duration no degradation in performance should be expected to occur; but in a situation where sustained performance occurs in a task which is not intrinsically challenging, degradation in performance should be expected.

4. Noise

Based on the publications of Roth and Boggs and Simon, McCormick devised a list of the types of tasks which are most likely to be affected by noise. These tasks include vigilance tasks, certain complex mental tasks, skill and speed tasks, and tasks which demand a high level of perceptual capacity. The final task type deals with time-shared tasks which stress the perceptual ability of the individual and appears to be a promising source of additional information (References 7,8, and 9).

Roth also points out that if noise is kept within reasonable hearing and safety limits there should be no expected degradation in performance.

"Perceived noisiness" is a term used by Kryter to identify noises which are annoying to people. The noise characteristics which are annoying are high frequency, high pitch, intermittancy and reverberation effects. This type of annoying noise can conceivably reduce an individual's performance through distraction.

5. Hours and Shifts

An important feature of work today is the need in many occupations and industries for work to continue throughout the twenty-four hours. This section will describe some of the physiological and psychological consequences of shift work.

The main physiological aspects are concerned with the existence in the body of diurnal rhythms (Reference 10). Nearly all the functions or states of the body which have been examined show a rhythmical pattern related to the 24 hours of the day. The best known is body temperature. In an individual who works during the day, body temperature rises from a low level early in the morning to reach a plateau about midday, and then it slowly falls again in late afternoon to a low level during the night.

It must be noted that when an alteration is made from a day shift to a night shift, these rhythms do not immediately change. The rate and degree of adaptation of the diurnal rhythms vary with the different rhythms.

Evidence is beginning to accumulate that diurnal rhythms do affect working efficiency. For example, there is some evidence that performance in a normal day's work shows a diurnal variation, rising during the day and falling off gradually in the afternoon. This rhythm of performance appears to be related to the body temperature rhythm.

There are a number of problems in the study of time shifts. A major one is the difficulty of separating and identifying sociological, psychological, and physiological effects. The individual who goes from a day shift to a night shift continues in a social environment geared to the usual pattern of day work and night sleep. These disturbing influences may be more severe or more serious than the physiological changes.

Insufficient detailed research on shift workers has been conducted to make it possible to state a preferable shift pattern. However, since physiological adaptation is variable and rather slow, indications are that either very short shift periods or very long ones, but not intermediate ones, may be best. Long shift periods mean remaining on, say a night shift for months or even years; a short shift means days, not weeks. A number of industries have adopted a two -two -three pattern; two days on early morning shift followed by two or three days on a night shift, then a rest period, followed by two days on the afternoon shift and three days in the morning.

The research on the effects of these very short shifts on physiological rhythms and performance is non-conclusive, but they appear to be more acceptable to workers than a five-day shift.

6. Fatigue

There is considerable difficulty in defining the word "fatigue" since it applies equally well to muscular and to mental work. The two aspects cannot be separated completely, but the physiological aspects dominate in considering muscular work, whereas the psychological aspects are predominant in fatigue related to tasks involving little muscular work. While it is hard to agree completely on a definition, there is a consensus among experts that as fatigue develops, performances declines.

As fatigue develops performance on a task becomes irregular. The various events do not follow each other in the same regular order as they do in the unfatigued stage. The timing changes, not all the phases slow down, but some do and, consequently, performance becomes less smooth. Some irregularities appear at first in short bursts, then the original timing is picked up again, especially if the operator has knowledge of results, but, then the irregularity returns and persists longer, with a shorter recovery period. The irregularities may then become gross and affect every phase of the task.

In tasks with a considerable perceptual element, where information is derived from a number of sources (auditory, visual, or tactile), as fatigue develops, the field of display becomes less adequately scanned and there are lapses of attention. These are more evident in a paced task where the operator has to work at a particular rate, on an assembly line, for example

Where there is a large visual display (as in a pilot's cockpit) with increasing fatigue, attention is paid more erratically to the display. The less essential elements may be increasingly ignored and attention concentrated on the most important dials and meters or, conversely, too much emphasis is placed on the peripheral elements at the expense of the central ones. The effect is that the right actions may be performed at the wrong times, and some actions may be left out.

Useful information on what actually happens in fatigue has come from more closely controlled observation of the details of performance. For example, it is sometimes found that the first effects of fatigue may be short-lived improvement of performance. The effects of fatigue have been found to be markedly specific. Thus, tests consisting of tasks different from the one causing fatigue generally fail to show any deterioration of performance. This can explain the frequent observation that changing one's work or activity is an effective way to combat fatigue. However, the alternative task must not be too similar to the fatiguing one (Reference 10).

Rest pauses during the working day are essential, and can prevent fatigue and increase production. The desirable length and frequency of such rest pauses are still uncertain, but the evidence suggests that short, frequent pauses, five minutes every hour for example, are more effective than longer rests at longer intervals.

An important element of fatigue is an increasing deterioration in the central processes involved in the organization of incoming information. Research is continuing on the physiological basis of the changes in the central nervous system which characterize fatigue.

One problem in the study of fatigue has been to distinguish it from boredom; the former may be said to result from overloading, the latter from underloading. This has now become an important aspect of vigilance tasks (monitoring radar screens, inspecting, etc.). The vigilance situation can be regarded as demanding, but boring, so there is a low level of arousal. If arousal or alertness can be increased, then it would be likely that overall performance would be improved, for example fewer signals would be missed or the response time would be quicker.

7. Personnel Selection and Training

a. Personnel Selection

A wide range of practical experience in many fields establishes the importance of proper personnel selection, training, and assignment, personnel selection results in the improved matching of human qualities to task requirements. This experience is especially critical when one realizes that work performance is not simply a matter of a person wanting to do well. The individual must have both the necessary skills and abilities for the given job and the perceptions of the behavior requirements of the job.

Personnel selection may be informal or highly formalized. In either case, it is imperative that there be a clear definition of the purpose the human operator is to fulfill in terms of a set of measurable criteria which are to be satisfied by his behavior. The personnel selection process must be based on an explicit understanding of the nature of the task. Figure G-7 summarizes the kinds of dimensions by which tasks can be described and compared to one another in terms of the requirements. Numerous other dimensions exist.

Certain predictions are typically chosen to determine the particular class of personnel which would be most likely to succeed in a particular job situation. Korman (Reference 11) summarized these predictors into the following categories:

- (1) Ability Tests: These consist of measures of verbal and other abilities such as memory, perceptual speed, special aptitude, inductive reasoning, etc.
- (2) Objective Personality Tests: These are measures of personality characteristics which have a relatively structured format, i.e., the individual respondent describes himself along dimensions defined by the test constructor rather than along dimensions defined by himself.
- (3) Projective Personality Tests: These are measures of personality characteristics which have an unstructured format and which allow the individual to respond along any dimension which he wishes and which he constructs.

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- 1 Decision making and communication activities
Develops budgets, supervises management personnel, verbal presentations, forecasts needs, variety of communications, personnel decisions
- 2 Hierarchical person-to-person interaction
Instructs supervises students, trainees, patients, subordinates, etc , issues directives, schedules work of others, interchanges information with prospective employees, students, or trainees
- 3 Skilled physical activities
Skill of hand tool usage, number of hand tools used, finger manipulation, estimates size
- 4 Mental vs physical activities
Positive loadings--deals with data, interprets information, intelligence, uses mathematics, clerical tasks
Negative loadings--manual force, moves objects by hand, deals with things
- 5 Responsible personal contact
Persuades, interchanges information with customers, clients, patients, etc , distractions from people seeking or giving information
- 6 Unpleasant vs pleasant working conditions
Uncomfortable atmosphere, unclean environment, noise, poor illumination, cramped work space
- 7 Varied intellectual vs structured activities
Positive loadings--interpretation of information, intelligence, usage of mathematics, occupation prestige
- 8 Man-machine control activities
Control operations, monitors work process, interpretation of information, responsible for physical assets
- 9 Intellectual vs physical activities
Positive loadings--"thinking" (vs "doing"), occupation prestige
Negative loadings--activity domain--things, repetitiveness, job structure
- 10 Physical vs sedentary activities
Positive loadings--standing, general force, manual force
Negative loadings--activity domain--data
- 11 Communication of data
Reporting, activity domain--data, interchange of information, written communication

Source McCormick, E J , J W Cunningham, and C G Gordon "Job Dimensions Based on Factorial Analyses of Worker-Oriented Job Variables," Personnel Psychology, 1967

Figure G-7. Selected Dimensions of Job Behavior
Useful in Personnel Selection

- (4) Objective Life-History Items. These consist of questions concerning relatively objective characteristics of a person's school, work, family, and personal background, the rationale for these is that they are measures of various attitudinal and personal characteristics of the individual which are not measured by other means
- (5) Interviews and Other Judgmental Assessments. These consist of judgments by various individuals as to the extent to which the individual possesses the behavioral characteristics which are felt to be necessary for adequate job performance.

Which of these are best? The answer depends on the criteria used, the occupations involved, various ethical problems, theoretical measurement problems, etc. Their usefulness depends on the given prediction situation and the given prediction problem.

b. Training

1) Principles

The identification of the essential features of training and their analysis has led to the establishment of several principles and the evolution of a number of techniques (Reference 11).

The first principle has been the recognition of the importance of giving feedback to the trainee of the results of his/her actions. It is important that this feedback be precise, easily understood, and occur as soon as possible after each trial. In cases where automatic equipment is used to aid or replace the trainer, this feedback can also furnish a continual record as to the level of accomplishment of the trainee.

The second principle, or characteristic, of training is the "learning" curve. When a repetitive task is performed, the time taken for each repetition, commonly called the cycle time, diminishes, at first fairly rapidly and then less and less until a fairly constant cycle time is reached.

The third principle in training is to analyze and break-down the particular task into its components. The task description would provide identification of each step required for performance of the task in terms of the action to be taken, the object to be manipulated, and the means

for determining that the step was performed correctly. The various dimensions which were cited earlier as being useful in describing tasks for personnel selection purposes can also be successfully applied in the training phase.

Additional questions related to training are "How should learning sessions be scheduled?" and "Should all the material be learned, be presented at once, or should a step-at-a-time approach be used?" Recent research on massed versus distributed scheduling of training sessions yield the following conclusions.

- (1) The harder the material to be learned, the greater the advantage of distributed practice over massed practice.
- (2) The less meaningful the material to be learned, the greater the advantage of distributed practice over massed practice
- (3) The lesser the ability of the trainee, the greater the advantage of distributed practice over massed practice

2) Techniques, Methods, and Devices

This section reviews some of the major training techniques and devices which are used in industry, their relative advantages and disadvantages, the kinds of situations in which they are useful, and why. The information presented is reported consistently in the literature; however, the discussion given by Korman (Reference 11), from which this information was based, had the merits of conciseness and good subject context

The lecture method, the first training technique, is a carry-over from the formal educational system. This method is disadvantageous in that actual skills necessary for a job (motor, interpersonal, or verbal) cannot be learned through the lecture method of training, thus making this type of training for jobs requiring these skills incomplete. It is limited to transferring conceptual principles, rules, etc. Secondly, it does not account for individual differences. All pupils would get the same training, regardless of their ability levels, interests, personality characteristics, and so on. A third problem with the lecture method of training is that for some people, such as individuals with low socioeconomic status, the great stress on verbal and symbolic understanding is anxiety-provoking. Finally, the

lecture method does not seem to be capable of meeting various conditions which seem to facilitate learning, such as feedback

The reasons often stated for using the lecture method, given these faults, include tradition and economy. The lecture method is the predominant mode of teaching in our formal educational system; the size of the class for a lecture is limited only by the characteristics of the communication medium used.

Simulation methods are also used for teaching and training individuals. By "simulation training methods" are meant those techniques in which the real task is reproduced, usually in a simplified form and without the complications involved in training on some large or expensive equipment which may be damaged. The essential value of this procedure is believed to be that it maximizes transfer of training possibilities.

The use and development of simulators, which are themselves often expensive, have proved extremely valuable in training but have also shown up some of the hazards of transferring a skill acquired from a simulator to the real-life situation. Most simulators have been engineered to provide such aids to learning as reinforcement, knowledge of results, and so on. However, in some real tasks there may be no such feedback. A second problem is that these simulation methods may often take on the aspects of a game rather than a training experience.

Finally, programmed learning consists of four basic features. One is that the training material is broken up into a series of basic components or discrete steps. Second, each of these steps (frames) are placed in order so that there is a logical progression. Third, at the end of each frame, the trainee is asked to make some kind of response which is designed to measure his comprehension of the material in that frame. Finally, the trainee is given immediate reinforcement and feedback as to whether he is correct in his response before going on to the next frame. Inherent is that the person controls his own pace while going through the program.

The method is, therefore, effective because it contains within it (1) reinforcement, (2) knowledge of results, (3) self-control

rather than authoritarian control, and (4) expected activity on the part of the trainee. All it really does not contain is a provision for transfer of training.

Figure G-8 provides a synopsis of the various stages of training and the training devices usually employed at each stage. Note that the devices are closely related to a particular type of technique as well as the stage of training.

3) Cost Effectiveness in Training

Cost effectiveness is usually the single guiding principle in devising a new training program and each of its elements. For training, cost effectiveness translates to achieving given training requirements with the minimal feasible cost in dollars. Toward this end, HUMRRO noted a number of considerations of modern training technology which must be recognized (Reference 12).

- (1) Organization of the training program around a functional context, that is, around sets of meaningful, purposeful, mission modules, and teaching training content in the context of the mission-oriented purpose it supports.
- (2) Individualization of training, that is, adapting the pace and redundancy in training to the rate of learning of each student and advancing a student to the next set of instructional content only after he has demonstrated mastery of an earlier set.
- (3) Sequencing of instruction, that is, arranging the order of instructional content so that there is assurance students have been taught (and have mastered) prerequisite knowledges and skills before training in a new set is undertaken.
- (4) Minimizing of equipment cost, that is, to the extent that is efficient, substituting training in devices or other less expensive equipment for the much more expensive training.
- (5) Avoidance of over-training, that is, assuring that training time is restricted to that needed to bring a trainee to the required level of proficiency and no more.

STAGES OF TRAINING	
• INDOCTRINATION	Trainee learns what tasks consist of and to go about performing them
• PROCEDURAL	Provides trainee with the essential nomenclature and knowledge concerning the sequence of performing task elements
• FAMILIARIZATION	Provides trainee with an opportunity to practice task procedures and learn something about the task dynamics
• SKILL	Allows the trainee to develop proficiency in performing the task
• TRANSITION	Required when a person who is skilled in the operation of one model of equipment must learn to operate another model of equipment

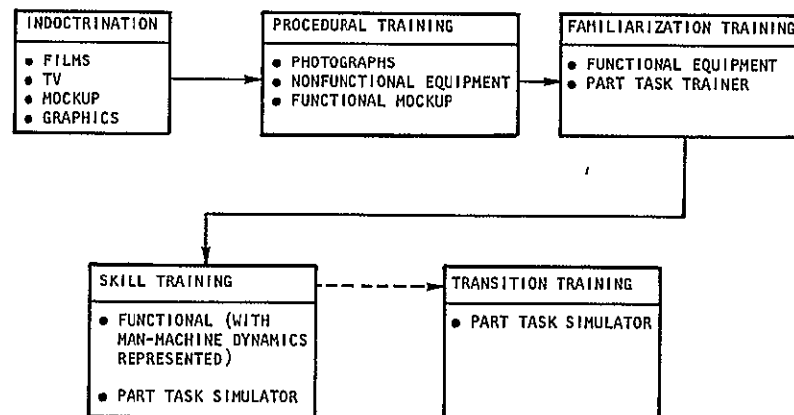


Figure G-8. Stages of Training and Associated Training Devices and Aids

- (6) Efficient utilization of personnel resources, that is, each instructor should be optimally qualified for his task, should be provided with the tools he may require for efficient use of his time and talents, and should have clearly stated and measurable instructional objectives to attain.

8. Human Relations

There is a remaining perspective on human factors analysis which has not been directly addressed, but impacts upon the performance of the individual and his relationship with all aspects of the working environment the influence of human relations. It is the individual's perception of his relationship with his working environment that influences his job satisfaction, morale, and motivation. As a harmony between the individual and his environment develops, his satisfaction will increase. Figure G-9 illustrates the interrelationship of a number of factors which impact on the motivation, performance, and productivity of the individual.

One of the important elements of the human relations perspective is communication. Communication can best be evaluated by examining the group interaction and influence and the leadership styles which are manifested in the organizational climate.

There is considerable research indicating that group size tends to be negatively related to work performance, independent of the measure of performance used. It is obvious also that decreasing the size of the unit can be done only up to a point since sufficient abilities and resources must be available to do the job. Korman approaches this by saying that there is probably an optimal number of individuals needed for performing a given job or task and that increasing the number will just decrease performance (Reference 11).

One area of great concern to psychologists interested in the performance of groups has been the effects of various kinds of communication structures on performance. Costello and Zalkind, as cited by Korman, give the following summary of conclusions that have been drawn from group communication structure research.

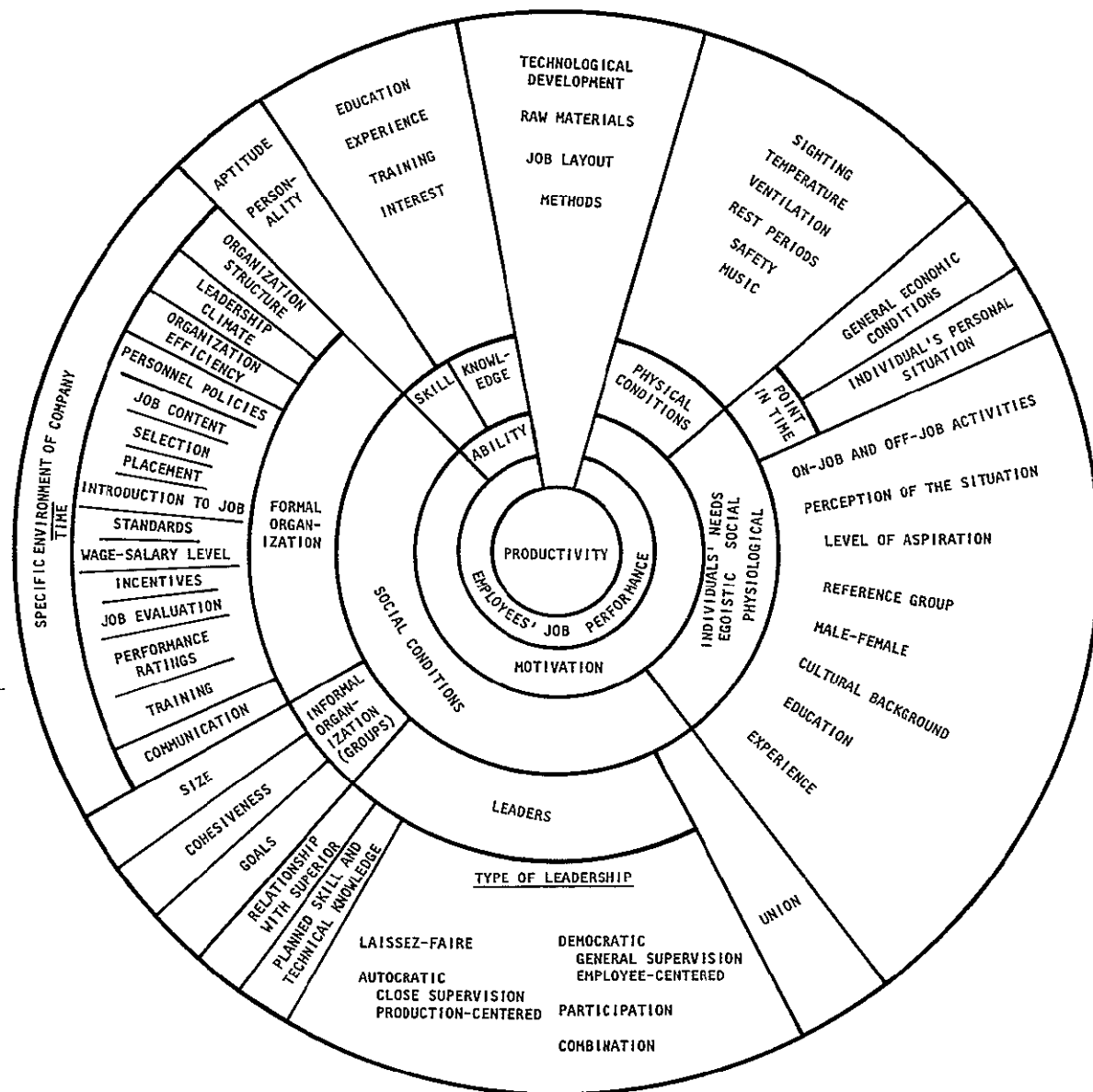


Figure G-9. Factors Contributing to Individual Productivity

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NOTE The author has provided several points which should be considered when reading the figure.

(1) The diagram consists of a series of concentric circles, each divided into segments. No attempt has been made to have the size of each segment reflect its relative importance. The importance of each segment would probably be different for each organization studied, for each department in the organization, and even for each individual employee with his own distinct needs.

(2) The factors in each segment of each circle are deemed to affect or determine the factors in the corresponding segment of the next smaller circle.

(3) The factors in each segment of each circle frequently affect and are affected by factors in some of the other segments in the same circle.

(4) The factors in each segment of each circle may also affect factors in segments elsewhere in the diagram.

(5) All the factors in the diagram are subject to change with time.

Source. Robert A. Sutermeister, People and Productivity. New York. McGraw-Hill Book Company, 1969.

Figure G-9. Factors Contributing to Individual Productivity (cont.)

Highly centralized communications networks tend to.

- (1) facilitate efficient performance of routine problem solving involving, principally, the assembling of information,
- (2) strengthen the leadership position of the member most central in the network (i.e. the one having the larger number of channels and the most information), and
- (3) result in a quickly stabilized set of interactions among members.

Communications networks low on centralization:

- (1) produce higher levels of satisfaction,
- (2) facilitate the handling of ambiguous and unpredictable situations, and
- (3) are likely to be more responsive to creative and innovative solutions.

Figure G-10 depicts the communication patterns used in small-group experiments.

Leadership is the result of interaction of the leader with the members of his group within a specific environment. Different problems, different groups, and different attitudes within the same group are among the many influences which call upon different leadership qualities.

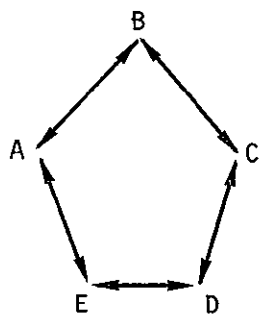
A comparison of leadership in small and large groups shows its situational nature. Typically, the leader of a small group has regular contact with each follower. In such situations, his personality carries more weight. As the organization grows, he is able to interact personally with only a few of the followers; consequently, new traits and skills are required.

The fact that is sometimes overlooked is that leaders within organizations are also followers.

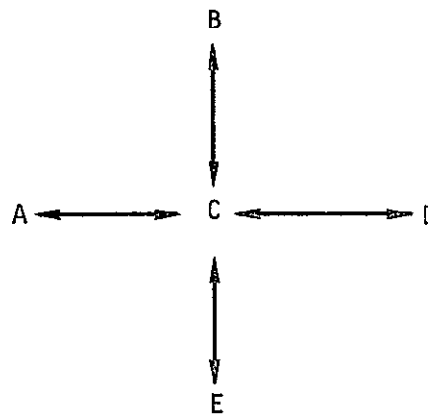
Certain characteristics tend to be found more in existing leaders than in their followers. Significant characteristics are intelligence, social maturity, inner motivation, and human relations attitudes.

The positive leader motivates his group by increasing their satisfaction. He takes the overall positive viewpoint that people naturally want to do good work if given the opportunity and the incentive. He makes sure his personnel are suited to the tasks they are assigned and explains why the work is being done.

- (1) The circle: A decentralized network in which all members are equally "central."
- (2) The wheel: A centralized network in which position C is central and all others are peripheral.
- (3) The chain: A moderately centralized network in which position C is central, positions B and D are intermediate, and positions A and E are peripheral.



(1) The circle



(2) The wheel



(3) The chain

Figure G-10. Communication Patterns Used in Small-Group Experiments

Leadership may be exercised in either an autocratic, participatory, or free-rein setting (Reference 13). An autocratic leader assumes full responsibility for authority over the work his group is doing. This allows quick decisions and provides strong motivation for the leader, if not for his followers. In a participatory leadership situation the leader plays a more managerial role. Although this system holds promise for achieving maximum productivity as a by-product of employee satisfaction, it is not clear that people adapt well to the demand for increased employee responsibility. A free-rein setting leaves the leader primarily in the role of a resource person. Such a setting is suited to projects requiring considerable creativity and individual initiative, but will often see members of the group proceeding at cross purposes.

Thus, as in all areas of human factors assessments, the particular goals of the organization and traits of the individuals making up the organization must be considered before adopting a leadership structure.

9. Problem-Solving and Human Relations Guidelines for Managing Change

People and their social systems tend to resist change because it upsets their patterns of adjustment and threatens their security. When people are under stress they are less apt to welcome habit or belief patterns different from their own. This behavior reinforced by the group can result in overt resistance to change. Since management initiates most change, it has primary responsibility for implementing it in a way that will encourage satisfactory adjustment. It is usually the employee who is changed and makes the final decision to accept it. Employee support is essential. The support of the employee can be obtained by convincing him that he will not suffer. This can be accomplished by protecting the employee from economic loss due to change and from decrease in status and personal dignity which sometimes results from economic loss. Grievance systems give the employee a feeling of security that his benefits will be protected (See Davis - Reference 13).

Communication is instrumental in reducing resistance to change. The full impact and nature of the change need to be made clear to those who will be impacted. Management can also reduce resistance by avoiding

unnecessary and trivial change. If individuals are plagued by numerous small changes, they will be less tolerant when asked to accept a major change.

Participation by those who will be affected is an excellent way to reduce resistance. It helps those affected to understand it, gives employees confidence, improves the plan for change with additional ideas, helps those affected feel they contributed to the change, sometimes stops poor plans, and broadens the outlook of the staff members who worked with the group. When management is controlling change, the best results are accomplished when the group participates in the recognition of need for change.

Resistance to change can be decreased if the employees recognize the need for change, understand how it will affect them, and participate in planning and implementing it.

Management can reduce resistance to change by avoiding unnecessary change, recognizing the possible effects of change and introducing it with adequate attention to human relations, sharing the benefits of change with employees, and diagnosing the problems resulting from change, and treating them.

B. M. Bass in Organizational Psychology presented a useful sequence of steps in three stages for managing change (Reference 14). The first stage involves perceiving the problem. The problem first must be sensed and analyzed. If dissatisfaction with current operations exists, and a problem is identified, then the boundaries of the problem should be specified. Once the boundaries are established, a judgment must be made - can the problem be resolved with routine programs or will a new solution have to be identified?

If the problem cannot be handled with a routine solution, step two begins searching for the solutions. When all alternative solutions within cost-of search limits have been identified and all criteria for selecting the best alternative have been determined, the alternatives must be evaluated and compared using all relevant criteria. Once this has been accomplished, step three can be approached.

Step three involves selecting the alternative. Here an alternative is selected and evaluated: has it been attempted in the past, what are the

similarities in the situations, was it successful? If the decision is that the alternative appears to be the best, it can be implemented with confidence that a logical sequence of decisions and the best answers provided the foundation for the decision.

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* THIS EXHIBIT SHOULD PROVIDE A USEFUL DEPARTURE POINT FOR ANY ADDITIONAL RESEARCH IN SUBJECT AREA RELATED TO HUMAN FACTOR ANALYSIS IN THE MOCC OPERATIONS CONTEXT

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APPENDIX H
COSTING DATA

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APPENDIX H
COSTING DATA

The following Appendix presents the derived costs of the NOCC system elements/STDN elements germane to the control of the network. The information is provided in a series of work sheets summarizing relevant cost data for CASMS, ASR, facilities, equipment, and personnel.

Computer System Cost

The first data sheet illustrates the cost of CASMS and is composed of entries for hardware, software development, documentation, and computer rental. The latter is required if development is performed prior to hardware investment or done on a time-sharing basis by a contractor. Documentation includes the publication of users manuals, program manuals, etc. The costing for ASR has entries similar to those for CASMS, but also includes interactive terminals for users. Estimates for all computer hardware, i.e., the central processor, peripherals, terminals, etc., were based on manufacturers estimated retail price.

Facilities Cost

Facility estimates were made with the assumption of new building construction and refurbishment of the present site. Cost estimating relationships (CER) for the new building were derived based on information provided in the Dodge Building Cost and Evaluation Guide and previous work done at BDM. Space requirements for the NOCC and support areas were estimated to be approximately 20 thousand square feet to adequately allow for near-term operational space requirements plus long-term growth. The interior finishing was broken out by simple interior and multi-partitioned, with the NOCC categorized in the former and the support area in the latter. Mechanical items included heating, ventilation, air conditioning, air filtering, and plumbing. In addition, special equipment and computer hardware requirements

doubled the mechanical CER for the NOCC. Refurbishment of the NOCC included interior finishing, mechanical items, and electrical work. It was assumed that the present facility would provide adequate support space and would not require refurbishment. Demolition, or "tear down," of the present NOCC was conservatively estimated to be fifty percent of the finishing costs.

NOCC Equipment Cost

Required equipment for the normal operations of the NOCC include CRTs, consoles, printers, and miscellaneous furniture. The CRTs and printers were costed based on manufacturer's estimated retail price ranges while the console structure and miscellaneous furniture were BDM estimates.

Personnel Cost

As discussed in the report, NOCC operations require one operations manager, two systems analysts, three controllers and two schedulers. All of these requirements dictate staffing twenty-four hours a day, seven days a week, fifty-two weeks a year, which result in five personnel per position. The skill levels of these positions were delineated in the study and were costed according to estimates from the government's General Schedule. In a similar fashion, the personnel support costs were calculated for programmers, technical support people, documentation people, service accountants, and planners. These costs are summarized on the Personnel Cost Data Sheet.

CASMS

COST DATA SHEET NO. 1

COST ITEM	UNIT COST	NO.	AGGREGATE COST	COMMENTS
A. HARDWARE			59K - 79K	MANUFACTURER'S ESTIMATED RANGE
B. SOFTWARE DEVELOPMENT		-	250K - 400K	BDM ESTIMATE
C. DOCUMENTATION			62.5K - 100K	25%
D. S/W DEV SUPPORT			50K - 80K	COMPUTER RENTAL
			<hr/> 422K - 650K	

ASR

COST DATA SHEET NO. 2

COST ITEM	UNIT COST	NO	AGGREGATE COST	COMMENTS
A. HARDWARE				
1. MINI			35K	MANUFACTURER'S ESTIMATED PRICE
2. TERMINALS			165K	75K (INTERACTIVE) 90K (PRINTERS)
B. SOFTWARE DEVELOPMENT			250K - 400K	BDM ESTIMATE
C. DOCUMENTATION			62.5K - 100K	USERS MANUAL, PROGRAM MANUAL
D. S/W DEV. SUPPORT			50K - 80K	COMPUTER RENTAL
			<hr/> 563K - 780K	
			528K - 745K	

NOCC STRUCTURE - NEW BUILDING

COST DATA SHEET NO. 3

COST ITEM	UNIT COST	AREA (FT ²)	AGGREGATE COST	COMMENTS
1. BASIC STRUCTURE	\$30/FT ²	20K	600K	(DODGE BLDG. COST AND EVALUATION GUIDE)
2. INTERIOR FINISH				
a. NOCC PLUS EQUIP.	\$7/FT ²	5K	35K	CER FROM PREVIOUS BDM EFFORT
b. SUPPORT	\$16/FT ²	15K	240K	CER FROM PREVIOUS BDM EFFORT
3. MECHANICAL ITEMS				
a. OFFICE AREAS	\$10/FT ²	15K	150K	CER FROM PREVIOUS BDM EFFORT
b. NOCC PLUS EQUIP.*	\$20/FT ²	5K	100K	BDM STUDY TEAM ESTIMATE
4. ELECTRICAL	\$7/FT ²	20K	140K	CER FROM PREVIOUS BDM EFFORT
			<hr/> 1,265K	
			1M - 1.5M	
*BDM ESTIMATED AN ADDITIONAL \$10/FT ² FOR SPECIAL EQUIPMENT AND COMPUTER HARDWARE				

NOCC STRUCTURE - EXISTING BUILDING/REFURBISH OLD

COST DATA SHEET NO. 4

COST ITEM	UNIT COST	AREA (FT ²)	AGGREGATE COST	COMMENTS
1. INTERIOR FINISH	\$7/FT ²	5K	35K	CER FROM PREVIOUS BDM EFFORT
2. MECHANICAL ITEMS	\$20/FT ²	5K	100K	CER FROM PREVIOUS BDM EFFORT
3. ELECTRICAL	\$7/FT ²	5K	35K	CER FROM PREVIOUS BDM EFFORT
			<hr/> 170K	
4. DEMOLITION			85K	BDM STUDY TEAM ESTIMATE
			<hr/> 255K	

NOCC EQUIPMENT
COST DATA SHEET NO. 5

COST ITEM	UNIT COST	NO.	AGGREGATE COST	COMMENTS
1. CRTs	2.5 - 4.0 K	12-16	30/48 - 40/64 K	MANUFACTURER'S ESTIMATED RANGE
2. CONSOLE STRUCTURE	3 - 5 K	12-16	36/48 - 60/90 K	BDM ESTIMATE
3. PRINTERS	10K - 15K	2	20 - 30 K	MANUFACTURER'S ESTIMATED RANGE
4. MISCELLANEOUS			5K <hr/> 91K - 189K	TABLES/CHAIRS/ BOOKCASES/ CABINETS, ETC.

PERSONNEL

COST DATA SHEET NO. 6

COST ITEM	UNIT COST	NO.	AGGREGATE COST	COMMENTS
A. NOCC OPERATIONS				
1. OPERATIONS MANAGER	22K - 33K	5	110K - 165K	GS 13-14
2. SYSTEMS ANALYST	17K - 26K	10	170K - 260K	GS 11-12
3. CONTROLLER	10.0K - 15.0K	15	150K - 225K	GS 6-9
4. SCHEDULER	8K - 12.0K	5-10	40K - 120K	GS 5-6
B. OPERATIONS SUPPORT				
1. PROGRAMMER	11.0K - 17.0K	1	11K - 17K	GS 6-9
2. TECHNICAL SUPPORT	17.0K - 25.0K	5	85K - 125K	GS 11-12
3. DOCUMENTATION	6K - 10K	1	6K - 10K	GS 5-6
4. SERVICE ACCOUNTANT	10K - 15K	4	40K - 60K	GS 6-9
5. PLANNER	22K - 33K	4	88K - 132K	
			<hr/> 700K - 1,114K	

ASR DEDICATED HARDWARE

COST DATA SHEET 7

ITEM	JUSTIFICATION	ROM COST (\$K)
CPU*	<ul style="list-style-type: none"> ● INTERCHANGEABLE WITH CASMS 	5.0 - 6.0
STORAGE 15-20 MILLION BYTES (DISC)	<ul style="list-style-type: none"> ● USER "TINKER" FILES ● MASTER SCHEDULE 	20.0 - 25.0
MAG TAPE DRIVE & COUNTR.	<ul style="list-style-type: none"> ● DIAGNOSTIC PROGRAMS, OPERATING SYSTEM, DATA LOGGING, ETC. 	8.0 - 10.0
PRINTER	<ul style="list-style-type: none"> ● STATUS REPORTS, SOFTWARE DEVELOPMENT SYSTEM CONTROL 	5.0
I/O		
INTERACTIVE TERMINALS	<ul style="list-style-type: none"> ● PROVIDE USER, INTERACTIVE ACCESS TO SCHEDULING ROUTING (EST. 30 REQ'D AT \$2-5K EACH) 	75
HIGH SPEED TELETYPE	<ul style="list-style-type: none"> ● PROVIDE USER INTERACTIVE ACCESS TO SCHEDULING ROUTING (EST 20 REQ'D AT 4.5K EACH) 	90

* SAME AS CASMS - SEE TEXT

CASMS HARDWARE
COST DATA SHEET NO. 8

ITEM	JUSTIFICATION	ROM COST (\$K)
CPU	<ul style="list-style-type: none"> • REQUIREMENT FOR R/T TASK • POTENTIALLY LARGE I/O • POTENTIALL LARGE BUFFERING 	5 0-6 0
STORAGE (65K)	<ul style="list-style-type: none"> • R/T DATA BUFFERING • SOFTWARE DEVELOPMENT • FOREGROUND/BACKGROUND OPERATING SYSTEM 	20 0-25 0
PERIPHERALS		
<ul style="list-style-type: none"> • MAG TAPE DRIVR & CONTR • DISC W/CONTR 	<ul style="list-style-type: none"> • DIAGNOSTIC PROGRAMS, OPERATING SYSTEM, DATA LOGGING, ETC • SHORT-TERM DATA, OPERATING SYS , USER PROGRAMS, DATA LOGGING 	8 0-10 0 8 0-15 0
<ul style="list-style-type: none"> • PRINTER • CARD READER 	<ul style="list-style-type: none"> • STATUS REPORTS, SOFTWARE DEVELOPMENT • DIAGNOSTICS, SOFTWARE DEVELOPMENT, SYSTEM CONTROL 	10 0-15.0 5 0
I/O		
<ul style="list-style-type: none"> • COUPLER CARDS • INTERACTIVE TERMINALS 	<ul style="list-style-type: none"> • INTERFACE I/O DEVICES WITH MINI • SYSTEM DESIGN 	1 0/CARD 2 5-4 5/TER

8-16 UNITS/CARD

APPENDIX I
PHASE III ANALYSIS RESULTS

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APPENDIX I
PHASE III ANALYSIS RESULTS

This appendix documents the results of the TDRSS Operations Control Analysis Study Phase III investigations. The Phase III analyses focused on critical operations control system issues as selected by NASA. Since these analyses are independent of the Phase I and II study, all Phase III results and conclusions have been incorporated herein.

Eight sections comprise this appendix. Each section corresponds to the individual technical submissions provided to NASA during Phase III. The ordering of the sections corresponds to the sequence in which the submissions were made. These submissions address five major areas. NCC Functional Requirements and Definition are addressed in Sections 1, 2, 4, and 6, Software Specifications are provided in Section 5; Manpower Estimates are discussed in Section 3; Section 8 addresses NCC Controller Manpower Requirements, and Section 7 presents Message Sizing and Data Rate Requirements

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SECTION 1

PHASE III TDRSS OPERATIONS CONTROL ANALYSIS STUDY

A. GENERAL

The Goddard Space Flight Center (GSFC) is the focal point for all NASA tracking and data acquisition operations which are not associated with the Deep Space Network (DSN). As a part of its overall mission, GSFC is responsible for providing a communications link between a spacecraft and its associated control center and experimenter(s). This communications link must support the transfer of required commands and spacecraft data between ground points and the spacecraft in a reliable, responsive manner. To this end, a configuration of facilities, communications systems and personnel has been established and termed the Spaceflight Tracking and Data Network (STDN). The STDN is currently planning for a major change in its configuration to occur with the advent of an operational Tracking and Data Relay Satellite System (TDRSS).

B. NCC RESPONSIBILITIES

The NCC, located at GSFC, will be responsible for the overall operational management of the STDN. This responsibility will include:

- (1) The provision of real time interface between the user and his spacecraft: this responsibility involves all operations control functions including real time or emergency scheduling, data monitoring and accountability, fault isolation and troubleshooting as well as testing and simulation involving network resources.
- (2) Provision of operations support in such areas as developing network support schedules, controlling changes in STDN operational procedures documentation, processing station requests for information, handling STDN administrative matters, and analyzing network service performance

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- (3) Provision of the technical expertise necessary for operation and maintenance of NCC equipment, development of NCC software and systems management.

C. NCC PHILOSOPHY

The 1980-1990 operations environment and potentially high user data rates dictate an automated approach to network operations management in general and to NCC operations in particular. To this end, it is planned to implement a system under which NCC functions are automated to the maximum extent possible.

D EXECUTIVE FUNCTION

The purpose of the EXECUTIVE function is to coordinate NCC hardware/software activities in support of STDN operations. It is broken into two tiers, a data router and a controller. In fulfilling the former of these two roles, the EXECUTIVE provides communications paths between all of the other functional areas. Many messages, such as status alarms, data requested from memory or test data, pass unimpeded through these paths simply being directed or routed to their appropriate destinations, unless there is some limit to available circuitry on which to transmit the messages. The EXECUTIVE is the central point of control, so that one message can be routed to all functions, or parts of a message can be routed to different functions, without the messages being sent more than once. For example, status alarms are displayed, but some status change message may also be sent to scheduling and to effected users.

The second of the subfunctions of the EXECUTIVE involves control of the operation of the NCC, and includes self-testing, executing the schedule trigger, controlling all input/output to the NCC system as well as internal interfacing, and adapting the NCC operations to failure or emergency

situations. The first of these areas involves a set of routine test procedures, to be executed either at predetermined intervals or on command, which insure that all other NCC functions are operating within acceptable tolerances. The schedule trigger could be viewed as a set of impulses or information packets to be sent to prepare and activate other NCC functions for support of upcoming scheduled activity. Thus the EXECUTIVE directs operations on the basis of an orchestration plan provided by scheduling.

If one mass storage area is used, the EXECUTIVE will have some data base management tasks, initiating the flow of data from memory to the functional area requiring that data (e.g., visibility data to scheduling), controlling access to, and read/writes in, the various files, managing data loading, and so on. If memory is distributed throughout the various function areas, these tasks would be parcelled out as well. Some interface tasks might still be necessary in the EXECUTIVE to control access to memory. All other I/O functions for the NCC as well as between the NCC and OSC are also provided by the EXECUTIVE.

Finally, the operational mode of the NCC is controlled via the EXECUTIVE. This includes providing "fail-soft" features by reassigning tasks to different sets of hardware in case of equipment failures and deletion of less important activities in case of emergencies or unavailability of equipment. There may also be inputs to the EXECUTIVE from system operators which change the frequency of self-testing for instance, or which determine how much user interaction there can be with scheduling. These inputs would be made in response to temporal exigencies.

E. SCHEDULING FUNCTION

The SCHEDULING function establishes and controls the timing of STDN resource allocation and NCC support activities, and monitors the accomplishment of scheduled tasks. Both preparation and real-time activities are subsumed in this function.

The schedule preparation can involve a high level of user interaction with the scheduler, though manual supervision of scheduling activity within

the NCC is maintained. The user service requests may be specific, generic, or quasi-generic. These requests are checked first against visibility data or predicts and then against already scheduled events for feasibility. A schedule is established for up to one month in advance. If conflicts arise between support requests, the SCHEDULING function attempts to resolve them, or if resolution is impossible, to provide users with alternative schedule times which still satisfy the users' needs. A mechanism is also provided within SCHEDULING to allow users to query the data base about schedule loading and to experiment with alternative schedule times on a "what if" request basis.

In addition to the schedule for allocation of network resources, a schedule of NCC support activities is prepared. This schedule is translated into the schedule trigger or initiator to be implemented by the EXECUTIVE

The real-time activities of SCHEDULING include response to emergency requests for support and monitoring the status of support operations and capabilities. The response to emergencies is a real-time version of schedule preparation, with the requestor being granted the desired support time or offered some alternative. The rapidity of response from the SCHEDULING function is of paramount importance here. The monitoring subfunction entails keeping track of the time, of what events are being executed and what ones remain to be accomplished, as well as of the status of any network elements which might affect scheduling. This monitoring could impact on the schedule trigger, as the necessary NCC functions may change in response to changing spacecraft or network status. The status monitor subfunction has initially been placed in the SCHEDULING function box; however, this type of activity seems more appropriate for the EXECUTIVE function, since it helps determine what operating mode is required, what activities should be given priority, and what NCC functions must be coordinated to support network activities. Perhaps discrimination capability should be placed in the EXECUTIVE to identify and transmit only those network status changes which do in fact impact on SCHEDULING.

F ACQUISITION DATA FUNCTION

The ACQUISITION DATA function will be responsible for monitoring Network acquisition and tracking information. This responsibility involves the transmission of state vectors (IRVs) to TDRSS and the execution of tracking tests. In fulfillment of TDRSS performance specifications requirements the ACQUISITION DATA function will provide to the TDRSS contractor, at the appropriate times, the user spacecraft state vectors computed by the attitude and orbital determination facility. The ACQUISITION DATA function will also accept acknowledgement of the reception of those state vectors.

The tracking tests to be performed will use spacecraft tracking data containing antenna angles and position components. State vector integration will be performed to determine range parameters. The results of the integration will be compared to predicted ranges generated by the attitude and orbital determination facility. The ACQUISITION DATA function will have the capability to perform this function for two separate spacecraft simultaneously. Discrepancies between the actual and predicted range parameters will highlight potential problem areas to NCC personnel.

G DATA MONITOR FUNCTION

The purpose of the DATA MONITOR is to assist in establishing real time estimates of data service quality. These estimates will be used to build the technical basis for service evaluation. This function will use a "trap sampling" scheme which selects and monitors the values of predetermined spacecraft parameters for out-of-tolerance conditions

The DATA MONITOR will "trap" n blocks of return link data being transmitted to the GSFC NASCOM switch via high speed digital channels from the STDN ground stations (TDRSS/GSTDN). Inputs from the SCHEDULING function will identify the appropriate NASCOM channels to be monitored, the spacecraft identification and return link data rate. A search of the "trapped" blocks will establish the required reference timing point. When a block containing the desired information is located, subsequent desired blocks

will appear at time intervals equal to the inverse of the return link data rate. Thus 'frame sync' is established

There will be m parameters established, one or more of which will appear in each spacecraft telemetry frame. From telemetry format information stored in MEMORY, these parameters will be extracted. Their values will be compared to tolerance thresholds which are also maintained in MEMORY. These comparisons will be performed by the DATA MONITOR hardware/software system. Out-of-tolerance conditions (alarms) will be made available to the PERFORMANCE MONITOR, TEST/SIMULATION; SCHEDULING, as appropriate, and to NCC personnel via the DISPLAY subsystem.

The result of the DATA MONITOR comparisons will be logged for subsequent use in establishing overall data service quality.

H PERFORMANCE MONITOR FUNCTION

The purpose of the PERFORMANCE MONITOR is to aid in the real time estimates of data service quality. The information from the PERFORMANCE MONITOR will be used for service evaluation and fault isolation and troubleshooting. The performance estimates will be established by monitoring a set of fundamental communication channel parameters, including the NASCOM PED indicator, and comparing parameter values to preestablished thresholds.

A number of thresholds may be established for each parameter which indicate various degrees of parameter degradation. These thresholds will be input data from NCC personnel. This mechanism will allow thresholds to be changed in response to operational situations

Each STDN ground station will provide a set of performance parameters to the PERFORMANCE MONITOR where they are compared to the predefined thresholds. Parameter comparisons will be recorded as part of the overall service quality evaluation data. Out-of-tolerance, or threshold crossing, conditions (alarms) will be made available to the DATA MONITOR function; SCHEDULING function, as appropriate, TEST/SIMULATION function and NCC personnel via the display subsystem. Hard copy information pertaining to the values of performance parameters is not precluded. Additionally the

capability to transmit performance parameter summaries to STDN users will exist.

As a result of information obtained from the PERFORMANCE MONITOR function, certain messages may be sent to STDN users. Since the information contained in these messages will be driven by the operational situation, their transmission by the PERFORMANCE MONITOR in an automatic response mode is unlikely. Therefore, the "transmit commands" responsibility of this function is not seen as a direct hardware/software function task.

1 TEST/SIMULATION FUNCTION

The TEST/SIMULATION function will assist in fault isolation, troubleshooting and provide the control for all NCC initiated test and simulation activities. Network tests and simulations will be supported by this function which will furnish simulation data in some situations and monitor on-going activities to determine deviations from desired results.

Alarms generated in the DATA MONITOR and PERFORMANCE MONITOR functions will be passed to the TEST/SIMULATION function. When problems are such that near real time resolution may not occur, this function will manage the tests/simulations required to aid in problem diagnosis and resolution.

Various simulation or test sequences will require that data be generated at the NCC and transmitted to appropriate network elements. At these elements, this data may be processed and looped back or hardware/software responses observed and recorded. In the former situation, the TEST/SIMULATION function will automatically compare the looped back responses with predicted responses and identify existing deviations. Deviations may be noted by personnel at the network elements and reported to the NCC by verbal and unformatted message techniques when loop back tests are not used.

In other tests and/or simulations, data may be transmitted from ground stations/users to the NCC to establish interface integrity. In these cases, the TEST/SIMULATION function will monitor the data and compare it to

expected results. Deviations from the desired results are provided to NCC personnel via the display subsystem.

J. ANALYSIS PLAN

This analysis effort was conducted in four steps, each of which increased the definition detail associated with the functions shown in the Composite NCC Functional Flow diagram. These steps are 1) description of functions identified in the composite NCC functional flow diagram, 2) development of NCC tasks and information requirements, 3) definition of hardware/software requirements, and 4) detached specification of operational concepts and procedures. Once the task and information requirements had been established, the last two tasks were conducted in parallel. Because the definition of the functions and their associated responsibilities were expected to change as the total operations control concept evolved, several iterations of the above steps, specifically steps 1 and 2, were expected. For the initial iteration, the first task was completed by 11 August 1976. The second task was completed by 13 August 1976. The final tasks were completed by 20 August 1976.

SECTION 2
NCC OPERATIONAL CONCEPTS AND REQUIREMENTS

A INTRODUCTION

This section presents estimates of NCC hardware/software system operational requirements. These requirements are expressed in terms of functions, subfunctions, tasks and elements which must be executed or accomplished within the NCC. In section 1, "Phase III TDRSS Operations Control Analysis Study," the NCC functions identified in the Composite NCC Functional Flow Diagram (Figure 1-2-1) were described. The following information refines these initial concepts. This refinement is presented in two major parts. the first treats the Executive function, the second addresses those functions which have been termed NCC Operations Support Functions (Scheduling, Data Monitor, Test/Sim, Performance Monitor, Acquisition Data). For each function identified five topics are addressed: functional description, processing requirements, which detail the sub-function, task and element requirements, assumptions associated with development of the above requirements, input/output message sizing and rates; and storage requirements. The material is presented in a bullet format, identifying the major attributes of the functions, subfunctions, and tasks in a shorthand form. Additionally, a flow diagram accompanies each functional description.

B EXECUTIVE FUNCTION

1. Description

The purpose of the EXECUTIVE function is to coordinate NCC hardware/software activities in support of STDN operations. It is broken into two tiers, a data router and a controller. In fulfilling the former of these two roles, the EXECUTIVE provides communications paths between all of the other functional areas. Many messages, such as status alarms, data

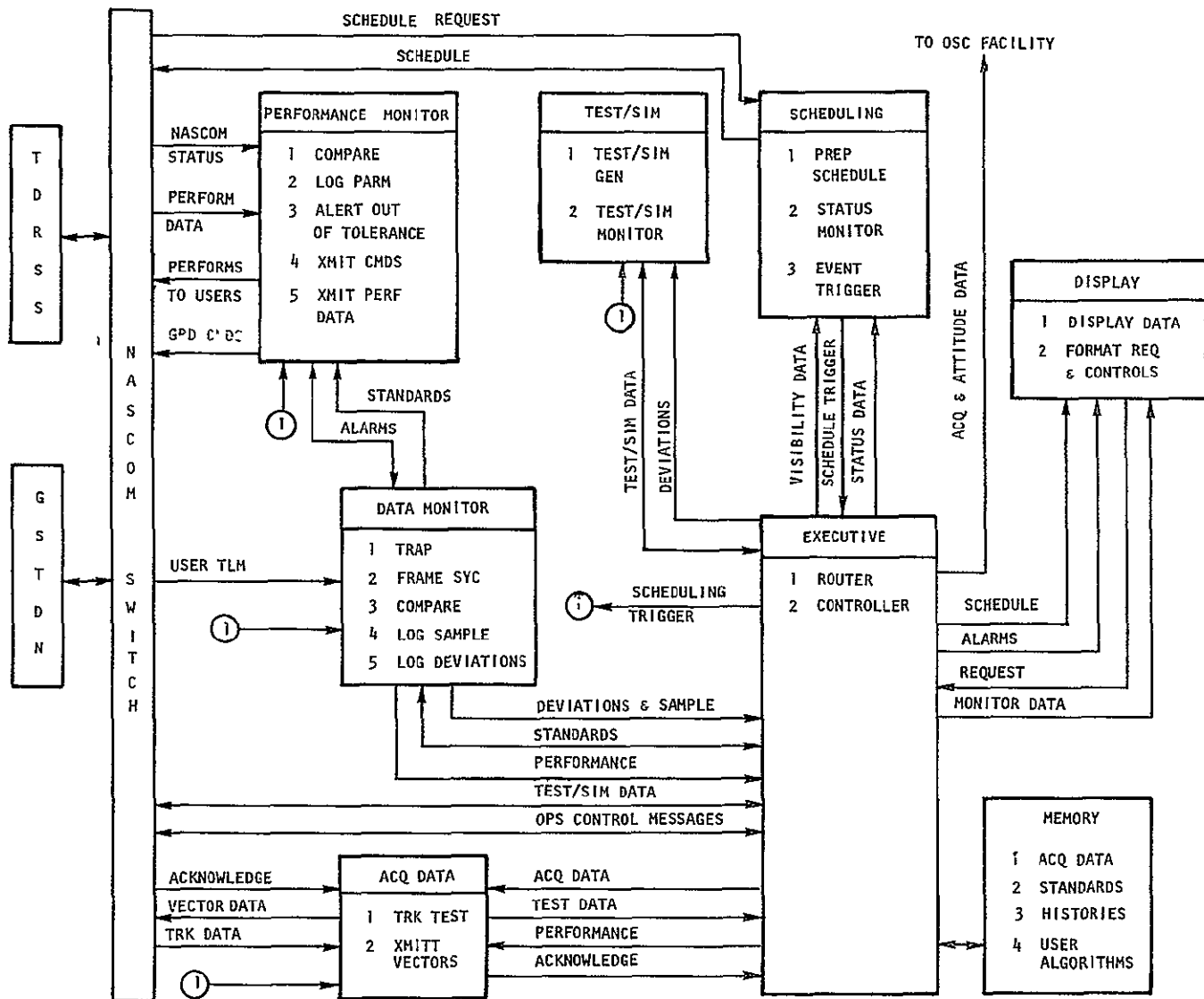


Figure 1-2-1. Composite NCC Functional Flow Diagram

requested from memory, or test data, pass unimpeded through these paths simply being directed or routed to their appropriate destinations.

The second of the subfunctions of the EXECUTIVE involves control of the operation of the NCC, and includes self-testing, executing the schedule trigger, controlling all input/output to the NCC system as well as internal interfacing, and adapting the NCC operations to failure or emergency situations. The first of these areas involves a set of routine test procedures, to be executed either at predetermined intervals or on command, which insure that all other NCC functions are operating within acceptable tolerances. The schedule trigger could be viewed as a set of impulses or information packets to be sent to the other NCC functions to activate and prepare them for support of upcoming scheduled activity. Thus the EXECUTIVE directs operations on the basis of an orchestration plan provided by scheduling.

If one mass storage area is used, the EXECUTIVE will have some data base management tasks: initiating the flow of data from memory to the functional area requiring that data (e.g , visibility data to scheduling), controlling access to, and read/writes in, the various files; managing data loading, etc. If memory is distributed throughout the various function areas, these tasks would be parcelled as well. Some interface tasks may still be necessary in the EXECUTIVE to control access to memory. All other I/O functions for the NCC as well as between the NCC and OSC are also provided by the EXECUTIVE.

Finally, the operational mode of the NCC is controlled via the EXECUTIVE. This includes providing "fail-soft" features by reassigning tasks to different sets of hardware in case of equipment failures and deletion of less important activities in case of emergencies or unavailability of equipment. There may also be inputs to the EXECUTIVE from NCC operators which change the frequency of self-testing for instance, or which determine how much user interaction there can be with scheduling. These inputs would be made in response to temporal exigencies. Status Monitoring was originally included under the SCHEDULING function but is included in the EXECUTIVE since it is a subfunction involving the ongoing execution of prescribed

activities within the NCC and thus more closely related to that function responsible for controlling the NCC hardware/software system.

2. Processing Requirements

An overview of the EXECUTIVE function and its relationship to the NCC support functions is shown in Figure I-2-2. The solid blocks identify the executive subfunctions. Each is described in turn below

a. Status Monitor and Configuration Control

1) Status Monitor

a) Message Authentication

- Validate formats
- Validate content
- Notify DISPLAY/Sender of Errors

b) Alarm Recorder

- Keeps track of alarms by source, type, spacecraft
- Notify controller if trend established

c) Resource Revision

- Receive Network Status Change Messages
- Message sent to DISPLAY for scheduling personnel review
- Update sent to scheduling resource data base
- Schedulers determine whether rescheduling is necessary and for what period of time, and then notify the Action Instigator

d) Internal Test Interpretation

- Determine response to bad test (hierarchical list of HW/SW)
- Verify Integrity of new on-line HW/SW
- Notify CONFIGURATION CONTROL of problems.
- Notify DISPLAY of trends/system crashes.
- Notes non-critical bad test results

2) Configuration Control

a) Resource Allocator

- Receive inputs from STATUS MONITOR
- Review current configuration listings

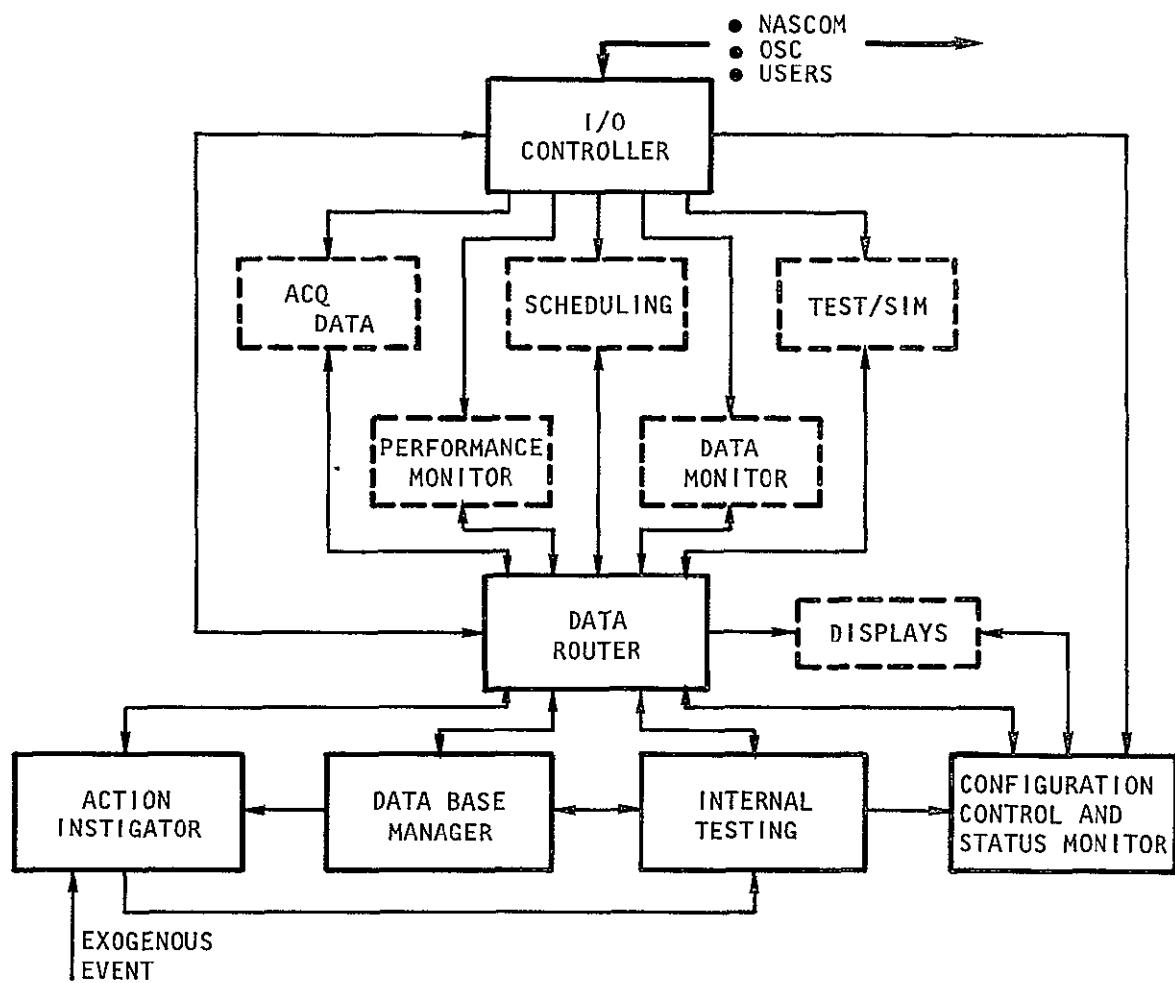


Figure 1-2-2. The EXECUTIVE Function

- Chart suggested revision of NCC resource configuration
- Send suggestion to DISPLAY
- b) Reconfiguration Activator
 - Receive Console commands ("Go ahead" on proposed reconfiguration)
 - Update files for Resource Allocator, maintaining information that the change has not been confirmed
 - Notify Action Instigator for interrupt
- c) Configuration Management
 - Receive notification of successful SW package change
 - Send Updates to Data Router-I/O controller message distribution tables
 - Send need for test message to Action Instigator
 - Receive confirmation of HW/SW reconfiguration
 - Validate updates of Resource Allocator files made by Reconfiguration Activator.
- b. Action Instigator
 - Coordinates the support activities of the NCC
- 1) Time Keeper
 - Acts as master timer for NCC
- 2) Generate Function Activity List
 - Read 8 hour Event Schedule from data base
 - Accept exogenous inputs for test or sampling frequencies
 - Receive inputs from Configuration Control
 - Mesh Schedule with required events for other NCC functions
- 3) Create Enablement Messages
 - Compare Activity List to system clock
 - Generate Enablement Message

- What function should do what, when
 - Necessary data to be read from storage
 - Send Message
 - Update Activity List
- 4) Inform Users
 - Notify user of beginning of his event
- 5) Function Interrupter
 - Notifies System Executive of desired interrupts
 - Provides direction for HW/SW reconfiguration to system executive
- c. Testing
 - Insures integrity of hardware/software systems internal to the NCC
 - 1) Receive enablement message from Action Instigator
 - 2) Choose test pattern
 - Translate enablement into appropriate test type
 - Retrieve pattern from data base
 - 3) Transmit Test Data
 - 4) Receive Response to Test
 - If no response then test is negative or change to red is indicated
 - Compare Test response to expected response
 - Grade response - good, bad, indeterminate.
 - 5) Send Test Results to STATUS MONITOR AND CONFIGURATION CONTROL
 - 6) Update Test Summary
- d. I/O Controller
 - Provides Interface between the NCC and the outside world
 - 1) Receive Message
 - Check Message type
 - Check Format
 - 2) Adjust Formats
 - Convert OSC inputs to proper format if necessary
 - Perform any other modification of messages

- 3) Provide Storage or Buffering
 - As it is necessary, provide area for getting messages safely off input lines
- 4) Forward Message
- e. Data Base Manager
 - Controls information in the system's memory, as well as access to that memory
 - 1) Receive Message and Validate ID
 - Determine the message sender is a valid user of the data base
 - Determine what file is being addressed
 - 2) Validate Access Right
 - Determine message sender has access to the addressed file
 - 3) Formatting
 - Assemble data from different files
 - Provide ability to "sort" on different criteria
 - 4) Data Delivery
 - Inform requestor or addressee of the location of his data
 - 5) Edit Inputs
 - Check format of input data
 - Check for reasonable values
 - 6) Record Data
 - 7) Maintain Tape of Data Base
 - Keep as backup
 - 8) Maintain Update Log
 - Show what was changed when
 - Indicates who uses system
 - 9) Configuration Management
 - Control what goes where
 - Reassignment of space
 - Control Files that vary in size with time

f. Data Router

- Switching center for information moving within the NCC

1) Receive message

- Check format
- Check completeness of message

2) Identification

- Identify message source and type
- Return incomplete message to sender

3) Interrogate message routing list

- Determine appropriate addressees based on message source and type.

4) Forward message

- Message is sent to all appropriate addressees

3. Assumptions

- With 1000 scheduled events per day, 600 events during the busiest shift (8 hrs) was used for sizing.
- An official clock will be designated for network synchronization, and this clock will be the time source for the Action Instigator
- The functions of the I/O Controller may be centralized in the EXECUTIVE, distributed throughout the system, or some mix of these two
- Internal communications requirements for the NCC can be met using short messages. These messages were assumed to be accommodated by 200 bits.
- Sizing is not driven by I/O rates except perhaps in the I/O Controller. Response rate is tied to desired response times of other functions and their workloads.
- Human approval is required for Configuration Changes or orders for schedule revision
- Since the EXECUTIVE is of highest priority ready backup must be provided

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4. Message Sizing/Rates

These are not considered a driving consideration in sizing the EXECUTIVE so they will not be specifically addressed.

5. Storage Requirements

a. Action Instigator Activity List

- Normal NCC Activity, heavy shift (600 schedule events)

1) Activity List Event Entry Format

Time of Activity	37 bits
HR - 5	
MIN - 6	
SEC - 6	
mSEC - 10	
μSEC - 10	
Function Address	6
Function Command	10
Correlated Schedule Event	
I D. (if appropriate)	<u>27</u>
Total	80 bits

2) Event List Entries

Data Monitor - checks 40%	240 entries
Performance Monitor - checks 100%	600
Acq. Data -	
Transmit IRVs	1
Monitor 40% of TRKS	240
Internal Testing - checks five	
functions once every 5 minutes	480
Scheduling - Required network	
scheduling modifications	<u>100</u>
Total	1661 entries

3) Total Storage Required

$$\begin{array}{r}
 1,661 \text{ entries} \\
 \times 80 \text{ bits per entry} \\
 \hline
 132,880 \text{ bits, subtotal} \\
 + 9 \text{ bits for day ID} \\
 \hline
 132,889 \\
 \approx 133\text{K bits of storage, total}
 \end{array}$$

b. NCC HW/SW System Status

$$\begin{array}{r}
 10 \text{ areas} \\
 \times 5 \text{ status level bits} \\
 \hline
 50 \text{ bits, total}
 \end{array}$$

c. NCC HW/SW Configuration List

- For 25 software packages resident in 10 pieces of ADP hardware

1) HW/SW Configuration

Hardware ID	10 bits
Resident software pkg	25
Operational State	<u>3</u>
Total	38 bits

2) Total Storage Required

$$\begin{array}{r}
 38 \text{ bits per HW piece} \\
 \times 10 \text{ HW pieces} \\
 \hline
 380 \text{ bits of storage, total}
 \end{array}$$

d. DBM Access List

$$\begin{array}{r}
 100 \text{ Files} \\
 \times 200 \text{ Users} \\
 \times 3 \text{ bits, accessibility code} \\
 \hline
 60 \text{ K bits, total}
 \end{array}$$

e. I/O Controller Message Table

1) Input

$$\begin{array}{r}
 10 \text{ bits, input message category} \\
 \times 10 \text{ bits, HW ID} \\
 \times 10 \text{ bits, port, ID} \\
 \hline
 1000 \text{ bits, total}
 \end{array}$$

2) Output

200 bits, user distribution flags	
$\times 100$ entries	
20 K bits, subtotal	
+ 2K bits, user port IDs	{ 200 user slots x10 port ID bits
22K bits, total	

f. Data Router Message Table

50 bits, message category
x 10 bits, HW ID
x 10 bits, port ID
5K bits, total

g. Internal Testing

- Internal Test data made available by simulated NASCOM block inputs of 4800 bits
- Ten such blocks were assumed to satisfy test data requirements

10 blocks x 4800 bits x 5 NCC Areas to Test
= 240K bits, total

h. Software Priorities List

- Size dependent on complexity of priority relationships and degree of operator responsibility for reconfiguration choices.

5 bits, function ID x 25 priority positions
= 125 bits, total

C NCC OPERATIONS SUPPORT FUNCTIONS

The remainder of this attachment considers the five NCC operations support functional requirements. The five functions, as defined in the NCC Composite Functional Flow Diagram are Scheduling, Acquisition Data, Test/Sim, Performance Monitor and Data Monitor. Requirements for each of these functions is presented in the same format used to describe the Executive requirements.

1. Scheduling

a. Description

The SCHEDULING function establishes and controls the timing of STDN resource allocation and support activities. Both forecasting and real-time activities are subsumed in this function.

The development of a forecast schedule can involve a high level of user interaction with the scheduler, though manual supervision of

scheduling activity within the NCC is maintained. The user service requests may be specific, generic, or quasi-generic. A forecast schedule is established for two weeks or more, but only for the coming week are specific times resolved to seconds or solutions to all conflicts for support provided. When conflicts arise between support requests, the SCHEDULING function attempts to accommodate all users, or if such accommodation is impossible, to provide users with sufficient information to help them find alternative schedule times which still satisfy their needs. A mechanism is also provided within SCHEDULING to allow users to query the data base about schedule loading and to experiment with alternative schedule times on a "what if" request basis.

The real-time activities of SCHEDULING include response to emergency requests for support and adjustment of the schedule to changing STDN support capabilities. A firm schedule is released either daily or for each shift and is changed only in response to these two types of requests. Both of these activities involve a real-time version of the forecast schedule preparation, with the requester being granted the support time he desires or being offered some alternative. The rapidity of response from the SCHEDULING function is of paramount importance here.

Status monitoring was originally included under the SCHEDULING function, but is included under EXECUTIVE since it is a subfunction involving the ongoing execution of prescribed activities within the NCC, and thus more closely related to that function responsible for controlling the NCC hardware/software system. An overview of the SCHEDULING subfunction flow is shown in Figure I-2-3. Dotted boxes are used to indicate areas external to the Scheduling function. The processing requirements for these subfunctions are described below.

b. Processing Requirements

The subfunctions and tasks for scheduling are described below.

1) Check ID

- Verify against a list of valid ID's that a requester may enter SCHEDULING.

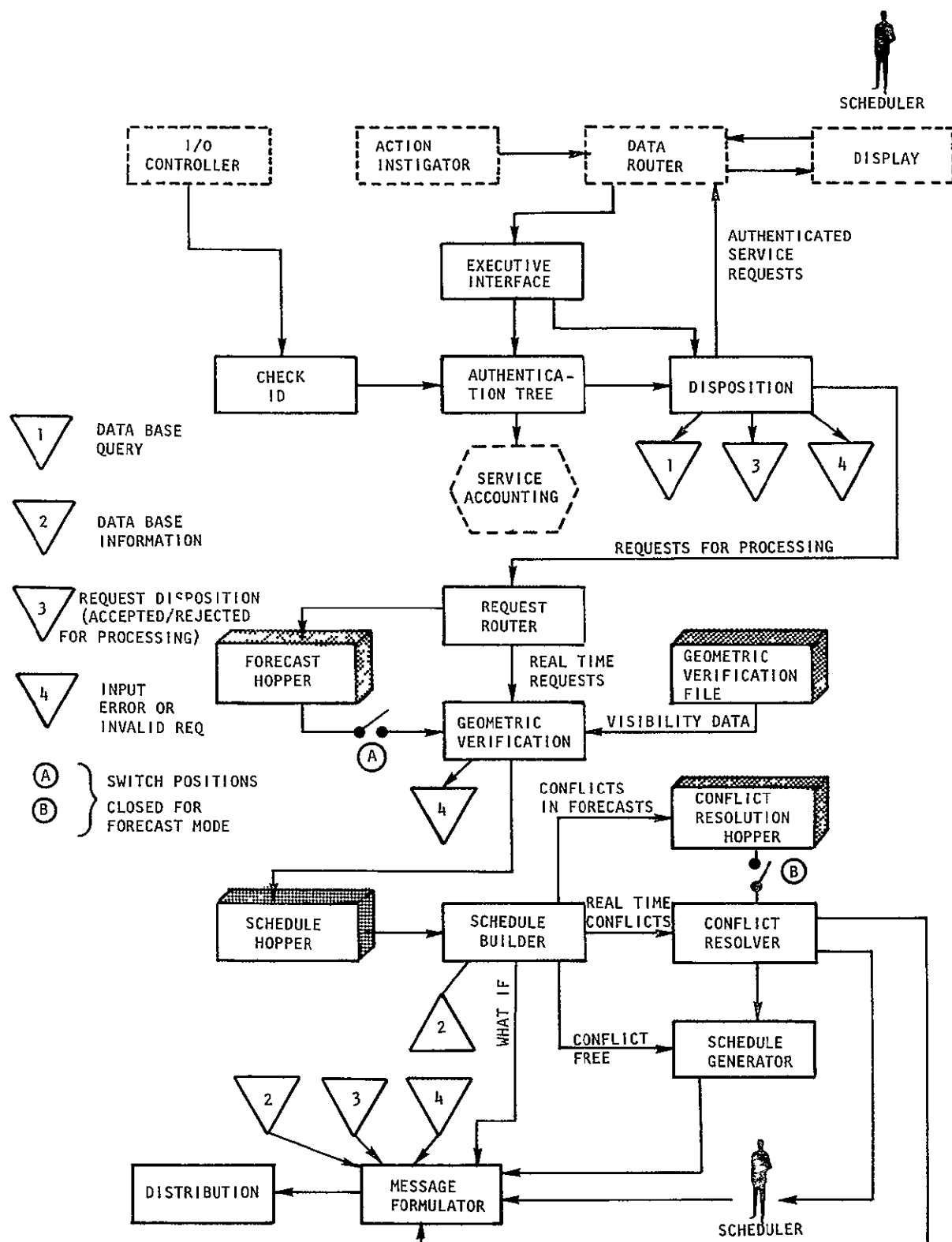


Figure 1-2-3. The SCHEDULING Function

2) Executive Interface

- Receives messages from the Action Instigator and controls changes in operating mode in response to those messages.
- a) Adjust list of legal requests in response to constraints (e.g., no 'what if's' for the next hour).
- b) Throw 'switches' human control vs human supervision, batch mode vs single schedule request.
- c) Permits the function to be checked or shut down by the EXECUTIVE.

3) Authentication Tree

- Determines that user inputs are in the proper form and are requests for legal functions.
- a) Format check.
- b) Check for completeness and reasonableness of data (data within expected bounds)
- c) Check for legal operation.
 - Not all users may schedule events.
 - Executive may provide time varying list of users who may use real time capability.
- d) Provide summary of user interactions to Service Accounting (statistical data).
 - Identify heavy users.
 - Control abuses of interactive capability

4) Disposition

- Routes valid and invalid requests to appropriate processor.
- Sends signal to initialize message to requestor that his request is under consideration.
- a) Data Base queries to DBM.
- b) Forward valid requests through display (human supervision) to Request Router.

c) Route unacceptable requests to Message Formulator for diagnostic response to requester.

5) Request Router

- Forward service requests to appropriate hopper
- Pass real time requests to Geometric Verification
- a) Differentiate forecast requests and conflict resolution requests.
- b) Pass on "real time requests, i e., "what if's", updates, or emergencies.

6) Forecast Hopper

- A file of requests for future service - beyond the time of the next week's schedule.

7) Geometric Verification

- Ascertains the visibility of a spacecraft from GSTDN or TDRSS antennae
- Compare request with Visibility Data
- Forward message
- a) Pass on verified request
- b) Initialize message to user if spacecraft not visible when requested.

8) Schedule Hopper

- A file of requests for the next week's schedule.

9) Conflict Resolution Hopper

- A file of conflict resolution requests to be scheduled.

10) Schedule Builder

- Lays out requested support against STDN support capability.
- a) Draw data from DBM.
 - For batch operations S/C parameters and STDN constraints
 - For single operations, relevant S/C parameters, STDN constraints, segment of schedule.

- b) Match requests with resources.
 - Detailed match of compatible hardware from GSTDN/TDRSS, NASCOM, etc , with satellite, user
 - Flag conflict areas.
- c) Forward Schedule information.
 - "What if" to user.
 - Conflict-free schedule to Schedule Generator.
 - Schedule with conflicts to Conflict Resolver.

11) Conflict Resolver

- Attempt to resolve conflicts identified in Schedule Builder.
- Notify human scheduler of inability to accommodate requests.
- a) Manipulate generic requests
- b) Describe unresolvable conflicts.
 - POCC's involved.
 - Duration of conflicts
 - Cause or source of conflict.
- c) Forward Message.
 - Schedule with resolved conflicts to Schedule Generator.
 - "What if's" to users.
 - Conflict messages to be displayed to a scheduler.
 - Schedule as it exists to Tentative Schedule file.

12) Scheduler

(Note Though not a hardware/software system element the role of the scheduler in conflict resolution is mentioned here to help make the accompanying flow chart more understandable.)

- a) Receive notice of conflicts not resolvable in the Conflict Resolver.

- b) Make further attempts at resolution.
 - Manually, or
 - Reinputting adjusted requests to the Conflict Resolver
- c) Imposing priority rankings as a last resort for conflict resolution.
- d) Forward Schedule with resolved conflicts to Schedule Generator
- e) Inform users, whose requests were bumped, of alternative schedule times.

13) Schedule Generator

- Finalize the forecast schedule or establish the updated schedule.

14) Message Formulator

- Format all SCHEDULING output
- a) Prepare messages to users.
 - Input errors, or request accepted
 - Conflict resolution message.
- b) Prepare data for Service Accounting.
- c) Format Schedule

15) Distribution

- Send SCHEDULING output to appropriate user or schedule recipient

c. Assumptions

- Provision for 5 simultaneous 'what if's' is made.
- Only requests from Scheduler hopper pass through Geometric Verification.
- 1,000 contacts per day is a bound for SCHEDULING load, including maintenance requests.
- Events are of a minimum duration of one minute.
- Three receiver and transmitter frequencies per S/C are allowed

d. Message Sizing/Rates

1) Input

a) Generic Requests for Service

Message ID - service request	3 bits
User ID	10
Service Request Type	
- generic or specific	2
Duration of Support	17
hr 5/min.6/sec 6	
Spacing - hr/min	11
Tolerance - min/sec	12
S/C Operating Mode	<u>83</u>
	138 bits, total

b) Specific Requests for Service

Message ID - service request	3 bits
User ID	10
Service Request Type	2
- generic or specific	
Date/Data Time	26
day 9/hr 5/min 6/sec.6	
Support Tolerance - min/sec	12
Resources Requested	5
ground stations, etc.	
S/C Operating Mode	83
Control Center I/F	10
Channel ID - 1000 ports	
Control Center Command	10
I/F Channel ID	
Message Class	<u>4</u>
	165 bits, total

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c) S/C Operating Mode Format

S/C Receiving Freq. - 2 bit	7 bits
MA, SSA, or KSA flag plus	
5 bits for count of no. of	
5 MHz increments from	
2202.5 MHz, allowable for	
SSA	
S/C Transmit Freq.	7
S/C EIRP - resolved to tenths	10
S/C Polarization - RCP or LCP	2
Acq. Sequence - 1 or 2	2
Acq Duration - 0 to 30 sec	5
Data Groups	3
- Serial or Parallel	
Data Rate - in bps	28
Data Format	2
- Coded or Uncoded	
Mode	2
Service Configuration	9
Tracking Configuration - one	4
way or two way, doppler	
or ranging	
	<hr/>
	81 bits, total

2) Output

- a) Informational Messages 100 bits, total
(input errors, etc)
 - b) Conflict resolution message
 - S/C ID (of "bumping" S/C) 8
 - Alternative time suggestion 43
- 51 bits,
total

e. Storage Requirements

1) Forecast Hopper Accumulation File

- Forecasting 10.5K entries per week
(1000 contacts per day + 500 overhead)
 - Schedule request = 1 entry
Total ~1.7 Mbits/week
- For three weeks, the total storage requirement is
5.1 Mbits

2) Schedule Hopper Accumulation File

- Input data to Schedule Builder
- Stores one week of scheduling requests
Total ~1.7 Mbits

3) Conflict Resolution

- For 500 entries per week, retained for no longer
than one week
Total ~82.5 K bits

4) Forecast File and Tentative File (per week)

Date of File	27 bits
Event Number	35
S/C ID	8
Station/TDRS ID	5
Acq. Time	27
Duration	16
Support Type	4
Interface Port ID	10
Nascom Port ID	<u>10</u>
	142 + 27
	<u>x 10K</u>
	1.7 Mbits

5) Spacecraft Parameters

S/C ID	8 bits
Receiver Freq.(s)	25 x 3
Data Rate(s)	25 x 3
Transmit Freq (s)	21 x 3
Service Configuration (MA, SSA, KSA, shuttle, etc.)	4
Power Mode	2
Polarization	2
Mode	2
Data Group	2
Data Configuration	2
Data Format (Convolutionally coded or not)	2
Coherent, Noncoherent	<u>2</u>

97 + 142 = 250 bits, total

100 S/C x 250 bits per S/C parameter

= 25 K bits, total storage requirement

6) Geometric Verification File

a) Predict Data Format

Satellite ID	6 bits
Day/Date	9
AOS Time (hr, min, sec)	17
LOS Time (hr, min, sec)	17
Masked AOS Time (hr, min, sec)	17
Masked LOS Time (hr, min, sec)	17
Key View Period Crossing Points (hr, min, XX & YY, up & down)	44

Point of Closest Approach	11 (hr, min)
	120 (elev. & range)
Path Across View*	-
Darkness Periods	34
(hr, min, sec, start & stop times)	
Spacecraft/STDN/Sun	
Alignment Period	34
(hr, min, sec, start & stop)	
S/C Attitude	20
Orbit Number	<u>15</u>
	361 bits, total

* The ACQ DATA function stores IRVs for all spacecraft, and also has the capability to compute predicted path data. For scheduling forecasts, ACQ DATA's IRV integrator/predictor could be used since there is no real time requirement. Further, in S/C emergency situations, ACQ DATA would compute data (e.g. S/C path data) which could be distributed to other functions as necessary.

b) Total Storage Requirement (per day) —

$$\begin{array}{r}
 361 \text{ bits per predict} \\
 \times 10 \text{ ground stations (TDRSS = 3)} \\
 \hline
 3610 \\
 \times 750 \text{ 50 S/C} \times 15 \text{ orbits per day} \\
 \hline
 2,707,500 \text{ bit total, for one day}
 \end{array}$$

7) Legal Operations File (time variable)

- One for Forecast, one for Schedule or distinguishing entries.

$$\begin{array}{r}
 200 \text{ users} \\
 \times 10 \text{ operation types} \\
 \times 4 \text{ bits per entry} \\
 \hline
 8k \text{ bits, total}
 \end{array}$$

- Where Operation Types are
 - What If
 - Data Base Query
 - Conflict Resolution Forecast
 - Request Update
 - a) Internal
 - b) External
 - Emergency
 - Maintenance

8) Conflicts File

Users in conflict	$N \times 10$ bits
Service Type	3
Reason	4
Time Parameters	$N \times 43$
	$53N + 7$ bits, total
	$= 500$ for $N < 10$

$$\begin{array}{r} 500 \text{ bits} \\ \times 500 \text{ entries} \\ \hline 250K \text{ bits, total} \end{array}$$

9) STDN Constraints File

Equipment ID	14
Capacity (frequencies, rates)	20
Status	<u>3</u>
	<u>37</u>

$10,000 \times \approx 40$

Total = 400K bits

2. Acquisition (ACQ) Data

a. Description

The ACQ DATA function is responsible for monitoring Network acquisition and tracking performance information. This responsibility involves the transmission of state vectors (IRVs) to TDRSS and GSTDN ground

stations and the execution of tracking performance tests. ACQ DATA will provide to the ground stations and the TDRSS contractor, at the appropriate times, the user spacecraft state vectors computed by the attitude and orbital determination facility and accept acknowledgement of the reception of those state vectors. In addition, tracking performance data from the orbital determination facility will be monitored according to performance standards.

Other real-time tracking tests will be performed using spacecraft tracking data containing antenna angles and position components. State vector integration will be performed to determine range parameters and the results of the integration will be compared to the spacecraft tracking data. ACQ DATA will have the capability to perform this function for two separate spacecraft simultaneously. Any discrepancies will highlight potential problem areas to NCC personnel.

An overview of the ACQ DATA subfunction flow is shown in Figure I-2-4. Solid boxes represent subfunctions of the ACQ DATA function, while the dotted boxes indicate areas external to ACQ DATA, but necessary for the understanding of the functional description. Detailed requirements are presented below.

b. Processing Requirements

1) Executive Interface

- Implements routine and emergency ACQ transmission sequences and other commands according to ACTION INSTIGATOR triggers
- a) Accept and implement unload/reload, suspend, and other software commands from ACTION INSTIGATOR.
- b) Request IRV file from the DBM following INSTIGATOR TRIGGER for routine transmission to sites.
- c) Direct real-time emergency transmission of IRV file to appropriate site in the event of station downs, data destruction at site, etc.

2) Availability Verification

- Responds to the availability of state vector data at ACQ FILE 1 which has been identified for transmission by ACTION INSTIGATOR

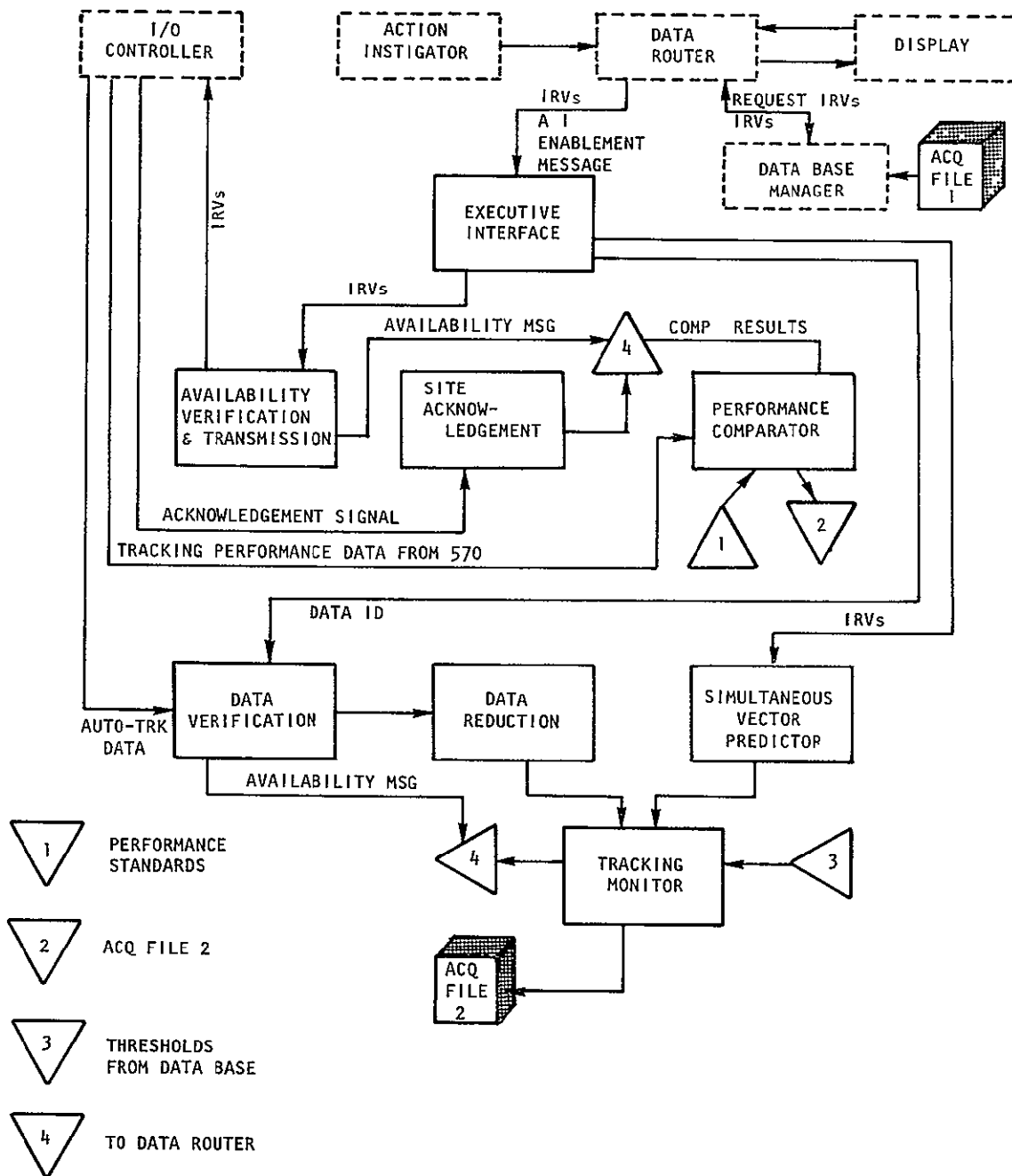


Figure 1-2-4. The ACQ DATA Function

- a) Notifies EXEC of unavailable scheduled ACQ DATA
 - b) Notifies EXEC of available scheduled ACQ DATA
- and transmits data to I/O controller for site destination in batches

3) Site Acknowledgement

- Responds to site acknowledgement of ACQ DATA State vector transmission
- a) Informs EXEC of successful transmission of acquisition data to site.
- b) Informs EXEC of failure at site to receive transmitted acquisition data

4) Data Verification

- Assures appropriate auto-track data is arriving for tracking tests.
- a) Receive auto-track data and compare with expected data as indicated by EXEC.
- b) Inform EXEC of receipt of appropriate or inappropriate auto-track data.

5) Data Reduction

- Modifies incoming auto-track data for interface with predicted data in tracking tests.
- a) By employing appropriate algorithms, reduce measured angles, round trip light times, and doppler measurements to the Cartesian position and velocity components of the standard state vector form.

6) Simultaneous Vector Predictor

- Generate a maximum of two simultaneous updated state vectors for tracking test comparisons with incoming auto-track data
- a) Accept at most two initial state vectors consistent with incoming auto-track data from ACQ FILE 1 in the DBM.
- b) By fourth-order Runge-Kutta integration, update vectors simultaneously to auto-track sample time and transmit to tracking monitor.

c) Results of Vector Predictor are available to other functions as necessary.

7) Tracking Monitor

- Performs comparison between modified auto-track data and predicted state vector data and displays results.

a) Compute first and second differences between position and velocity components of modified auto-track and predicted state vectors.

b) Compare differences with predefined tolerances available at the DBM

c) Display identified deviations, and initiate statistical summary of tracking tests including mean differences and relevant standard deviations.

8) Performance Comparison

- Compare tracking performance data with standard parameters.

a) Accept real time performance data (such as AGC of tracking receiver, frequencies, etc) from Code 570 and corresponding standard/threshold values from the DBM

b) Execute a performance parameter comparison and display and store results.

c. Assumptions

- Maximum of 1000 contacts/day
- Capability to perform two tracking tests simultaneously.
- Code 570 generates acquisition data for the DBM with sufficient lead time for batch transmission to sites
- First and second tracking test differences provide sufficient characterization for deviation identification
- IRV characters represent 6 bit bytes.
- Auto-track vectors are sampled every 30 sec for 2-10 min tracking support intervals every 2 hours (Reference 11).

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d. Message Sizing/Rates

1) Input

a) IRVs from DBM To ACQ Initiator

Size One IRV 47 char @ 6 bits/char = 282 bits
 1000 IRV/day x 7 day/week = 1.974 Mb/batch

b) Auto Track Data

Size LSD tracking format = 672 bits

HSD tracking format = 1200 bits

Rate From GSTDN 56 KB/s

From TDRSS 9.6 KB/s

Frequency: Every 30 sec for 2-10 min support/per spacecraft

c) Tolerances from DBM to Tracking Monitor

Size 3 position tolerances: 12 bytes @ 8bt/byte = 96

3 velocity tolerances. 12 bytes @ 8bt/byte = 96

d) Input Messages 192 bits
 { SITE ACKNOWLEDGEMENT
 TRACKING DATA ID

Size Header Info 5 bytes 40

Satellite ID Code 2 bytes 16

Vehicle ID 2 bytes 16

Message 5 bytes 40

112 bits

2) Output

a) IRV to I/O Controller

Size 1 IRV 47 char @ 6 bits/char. = 282 bits

1000 1Kb/day x 7 day/week = 1.974 Mb/batch

b) Output Messages { DATA ON SITE/NOT ON
 TRK DATA ACK TO EXEC
 REQUEST IRV

Size Same as input messages = 112 bits

c) <u>Messages to DISPLAY and Storage</u>			
<u>Size</u>	Header Info	5 bytes	40
	Satellite ID Code	2 bytes	16
	Vehicle ID	2 bytes	16
	Orbit No	2 bytes	16
	Position deviations		
	(10 vectors/tracking support)		
	x (3 positional deviations)		
	x (4 bytes/deviation)		
	x (8 bits/byte)		960
	Velocity deviations		<u>960</u>
			2008 bits

d) Storage Requirements

1) ACQ File 1

This file contains the initial acquisition vectors for each spacecraft to be acquired in a 24-hour period. It is generated at Code 570, stored as ACQ FILE 1 in the DBM, and accessed by the EXECUTIVE INTERFACE of the ACQ DATA function.

Size (1000 contacts/day) x (1 IRV/contact)
x (282 bits/IRV) = 282.0 Kb/day
(1 974 Mb/week)

2) ACQ File 2

This file contains a statistical summary of tracking test results as well as a summary of performance parameter comparisons. Mean deviations in each of three position and velocity parameters (and associated standard deviations) representing the tracking support per spacecraft per day are stored

<u>Size</u>	Satellite ID CODE	2 bytes	16
	Vehicle ID	2 bytes	16
	Three 24-hr positional		
	tracking deviation means	12 bytes	96
	Three 24-hr velocity		
	tracking deviation means	12 bytes	96

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Standard deviations	24 bytes	<u>192</u>
		416 bits
(30 spacecraft/day) x 416	=	12 5 Kb
Performance parameter		
comparisons	~12Kb	
		TOTAL = 25Kb

e) Summary

ACQ DATA incorporates the execution of two general functions acquisition data transmission/acknowledgement, and tracking and performance testing. These functions are supported by eight subfunctions

- (1) Executive Interface
- (2) Availability Interface
- (3) Site Acknowledgement
- (4) Data Verification
- (5) Data Reduction
- (6) Tracking Monitor
- (7) Vector Predictor
- (8) Performance Comparison

In support of these subfunctions, two main storage files are introduced ACQ FILE 1 - a list of acquisition vectors (and appropriate identifiers) for each of the desired contacts for a specified period (1.974 Mb/week), and ACQ FILE 2 - a statistical summary of tracking test results (12 5 Kb/day)

3 TEST/SIM Function

a Description

The TEST/SIMULATION function will assist in fault isolation, trouble-shooting and provide the control for all NCC initiated test and simulation activities. Network tests and simulations will be supported by this function, which will furnish simulation data in some situations and monitor ongoing activities to determine deviations from desired results in others

Alarms generated in the DATA MONITOR, PERFORMANCE MONITOR, and ACQUISITION DATA functions will be passed to the TEST/SIMULATION function

These alarms will alert TEST/SIM personnel to the potential requirement for troubleshooting tests. When problems are such that near real time resolutions may not occur, this function will manage the test/simulations required to aid in problem diagnosis and resolution

The specific responsibilities of this function are to perform launch simulations, troubleshooting tests, interface tests and other tests/simulations as required. An overview of the TEST/SIM subfunctional flow is provided in Figure I-2-5; solid boxes indicate the subfunctions of TEST/SIM.

1) Launch Simulations

During launch simulations this function assumes a management focal point role. Minimal hardware/software activities are conducted in this function. Since a launch simulation is a portrayal of actual expected events, the DATA MONITOR, PERFORMANCE MONITOR, and ACQUISITION DATA functions would be utilized in their usual capacities. Thus, overall processing requirements in this function are likely to be limited to the logging of results obtained from comparisons and checks performed by the three functions identified above.

2) Troubleshooting Tests

To execute tests related to the isolation and diagnosis of STDN data service degradations, TEST/SIM operators will select the test or tests which are to be performed. Upon specification of these tests, the TEST/SIM hardware/software system will construct the test enablement message. Upon receipt of this message at the STDN elements, predefined test sequences will be executed. The results of the test(s) will be transmitted back to the TEST/SIM function where they are interpreted.

3) Interface Tests

These tests are assumed to be conducted in a "loop back" mode utilizing off the shelf digital communications test sets. This hardware transmits, receives, synchronizes and displays error rates under pseudo-noise conditions. Outputs from this device or devices is provided to the data logger for analytical/service accounting/historical purposes.

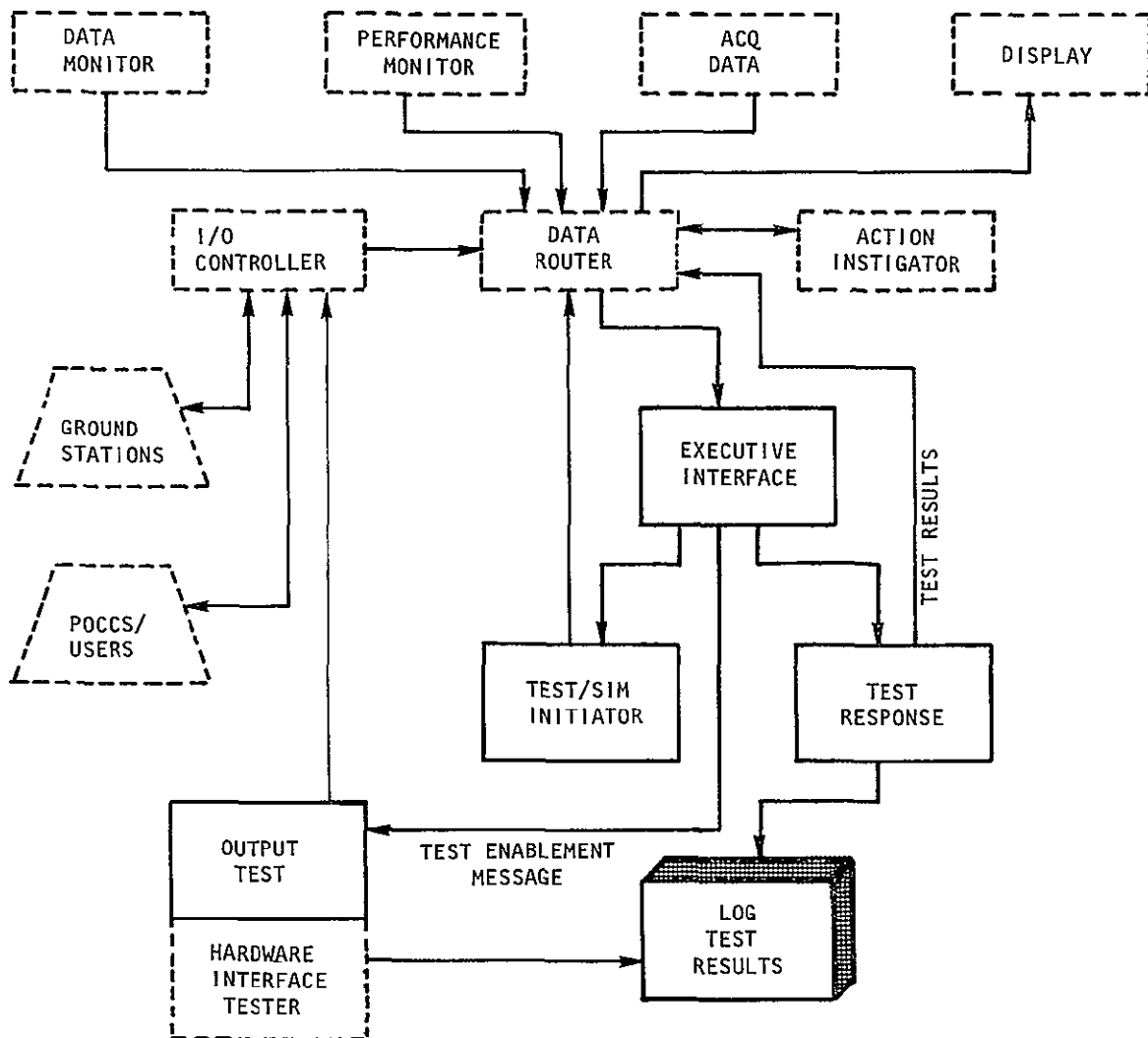


Figure i-2-5. The TEST/SIM Function

4) Other Tests/Sims

During certain tests data will be transmitted from the NCC to ground stations. In such cases specific data sequences will be transmitted from the TEST/SIM function. These data sequences will test ground station hardware/software modification integrity. Similar to other test activities described above, results of the test sequence will be transmitted to the TEST/SIM function for interpretation

b. Processing Requirements

1) Executive Interface

- Responds to directives from the ACTION INSTIGATOR to load or unload TEST/SIM software in appropriate hardware.
- a) Load software task
- b) Unload software task
- Routes test initiation message.

2) Test Initiator Subfunction

- Responds to directives from the ACTION INSTIGATOR or PERSONNEL manning control consoles to initiate procedures for the following
 - PRE PASS TESTS
 - LAUNCH SIMULATIONS
 - TROUBLESHOOTING TESTS
 - INTERFACE TESTS
 - VARIOUS OTHER TESTS
- Notifies console controller that appropriate test/test message is ready.

3) Output Test Subfunction

- Receives console operator activation.
- Builds test activation message for each station.

4) Test Response

- Receives results of station configuration tests
- Scans status indicator to determine whether station is configured correctly

- Makes loopback comparisons and indicates status
- Transmits status to consoles and data logger.

5) Data Logger

- Compiles statistics on test results

c Assumptions

- Test Scenario changes for the TEST/SIMULATIONS function will be made at times when machine is disabled. New TEST/SIM scenario will be loaded, no real time reloading
- Configuration checkout packages are resident in station software, thus, the tests are initiated from NCC (Transmission of actual test data, rather than messages, from NCC and back increases possibility of data corruption).
- Prepass test are configuration verification and interface integrity tests
- There are consistent equipment configurations for all stations for each spacecraft, e g , configuration for OSO the same at Madrid or Rosman
- Messages transmitted in 4800 bit blocks.

d Message Sizing/Rates

- Significant message sizes or response rates were not identified for this function.

e. Storage Requirements

- Data logger storage estimates were not made for this function It was assumed all required information would be directly written to magnetic tape at either this function or the DATA MONITOR, PERFORMANCE MONITOR, or ACQUISITION DATA as appropriate

4 Performance Monitor Function

a. Function Description

The purpose of the PERFORMANCE MONITOR is to give real time estimates of data service quality. The information from the PERFORMANCE MONITOR will be used (in conjunction with information provided by the TEST/SIM function, the DATA MONITOR function, etc.) for service evaluation, fault

isolation, and troubleshooting. The performance estimates will be established by monitoring a set of fundamental communications channel parameters, including the NASCOM PED indicator, and comparing those parameter values to pre-established thresholds.

A number of threshold levels may be established for each parameter to indicate various degrees of parameter degradation. The threshold values will be input from NCC personnel. Such a mechanism will allow for changes in those threshold values, in response to operational situations.

Each STDN ground station (including TDRSS) and NASCOM will provide a set of performance parameters. Parameter comparison results will be recorded as part of the overall service quality evaluation data. Threshold violation alarms will be made available to the DATA MONITOR, SCHEDULING, and TEST/SIM functions, and also to NCC personnel via the display subsystem. Acquisition of hard copy information, e.g., performance parameter summaries, is not precluded. Additionally, performance parameters will be distributed to users.

As a result of information obtained from the PERFORMANCE MONITOR function, certain messages may be sent to STDN users. Since information contained in such messages will be driven by the operational situation, their transmission in an automatic response mode is unlikely. Therefore, the "transmit commands" responsibility of this function is not seen as a direct hardware/software task.

An overview of the subfunctional flow for the PERFORMANCE MONITOR is shown in Figure 1-2-6; solid boxes are PERFORMANCE MONITOR subfunctions.

b Processing Requirements

1) Executive Interface Subfunction

- Responds to start-up/shut-down procedures
- Responds to directives from the ACTION INSTIGATOR or NCC personnel to channel messages to the LINE SELECTOR and MESSAGE PROCESSOR, in order to adjust the performance parameter "viewing window."

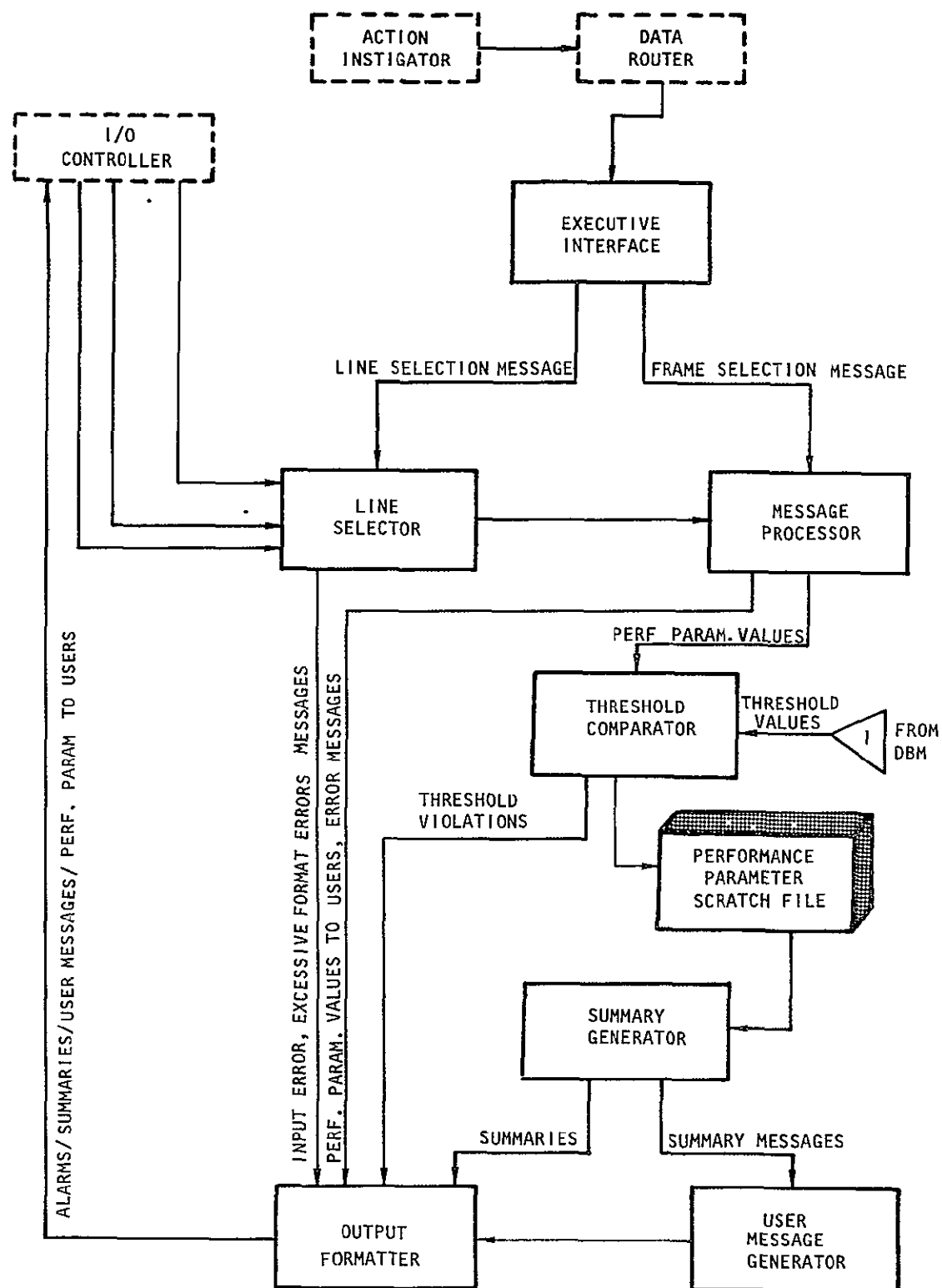


Figure 1-2-6. The PERFORMANCE MONITOR Function

2) Line Selector Subfunction

- Responds to directives from the executive interface to select performance parameter data from the appropriate (any or all the) ground stations

3) Message Processor Subfunction

- Checks performance parameter data for format errors
- Notifies the OUTPUT FORMATTER of input format errors, and also keeps a running count of the number of detected format errors.
- Sends performance parameter values to Output Formatter, to be transmitted to users

Subtasks

- a) Compare formats to an allowable set.
- b) Counts format errors and compares the rate to a predetermined level [Since format errors could be due to input errors, or a faulty checking process, subtask b self monitors the checking process.]
- Responds to directives from the Action Instigator to select the appropriate 60 bit performance parameter frames that arrive in the NASCOM 4800 bit block format.
- Sends appropriate performance parameter frames to the THRESHOLD COMPARATOR
- Notifies the OUTPUT FORMATTER if unable to find the appropriate performance parameter frames.

4) Threshold Comparator Subfunction

- Compares performance parameter values from the MESSAGE PROCESSOR to threshold values provided by the DATA BASE MANAGER.

- Flags out of tolerance performance parameters and sends them directly to the OUTPUT FORMATTER
 - Sends all the threshold comparison results to the performance parameter scratch file.
- 5) Summary Generator Subfunction
- Performs calculations on performance parameter values to generate statistical summaries.
 - Transmits the summary information to the OUTPUT FORMATTER and the USER MESSAGE GENERATOR.
- 6) User Message Generator Subfunction
- Receives performance parameter summaries from the SUMMARY GENERATOR and sorts them by user
 - Prepares user summary messages and sends them to appropriate addressees
- 7) Output Formatter Subfunction
- Receives messages and summaries and performance parameters from the other subfunctions
 - Formats the messages so the DATA ROUTER can send them to appropriate addresses.
 - Forms alarms in response to out of tolerance conditions, formats them and sends them to the DATA ROUTER.
- c. Assumptions
- The PERFORMANCE PARAMETER MONITOR will be sized to accommodate processing every performance value, from each ground station
 - Users can be provided performance parameter summary information, as requested.
 - The actual performance parameter values from the Message Processor will be transmitted to the users, on periodic, most recent value basis.

- Performance parameter values will come in from the ground stations at 9 6 KB/SEC rate, in NASCOM 4800 bit block format.
- Performance parameter frame is 60 bits long.
- Sizing allows for 128 different types of performance parameters.
- Sizing is done for inputs from 7 ground stations plus TDRSS plus NASCOM
- The reporting facilities can give up to 25 performance parameters.

d. Messages Sizes/Rates

1) Input Messages

a) Inputs to the Executive Interface

MESSAGE I.D	3 BITS
TIME	27
LINE(S) SELECT	10
PORT/LINK I D	11
PARAMETER I.D.	<u>7</u>
	58 BITS

b) Inputs to Line Selector

Each ground station (7), NASCOM and TDRSS will provide performance parameters at a 9 6 KB/SEC rate. The performance parameter frame is 60 bits long (potentially 75 different frames in a 4800 bit block)

PERFORM PARAM. FRAME	60 BITS
MESSAGE I D	3
PORT/LINK I.D.	11
TIME	27
PARAMETER I D.	7
PARAMETER VALUE	12

All possible combinations of 9 different input lines 10 bits

2) Output Messages (To Output Formatter)

a) Upon user request, performance parameter values will be available output from the message processor on a periodic basis

60 bit performance parameter frame

b) The message processor will transmit a message indicating any inability to find a performance parameter

58 bit input message

+2/bit error flag = 62 bit message

c) The line selector could send two messages to the output formatter.

• Format error msg. 62 bit msg

• Excessive error rate 8 bit msg

d) The threshold comparator will flag threshold violations and send an alarm to the output formatter.

MSG I D	5 BIT	5
ALARM I D	5	5
ABOUT WHOM I D.	20	20
CRITICALITY	5	5
PARAMETER I D.	175	7
PARAMETER VALUE	625	25
THRESHOLD CROSSED	625	25
NEXT THRESHOLD	<u>625</u>	<u>25</u>
	2085=MAX	117=MIN

e) Summary Messages

MESSAGE I.D.	3
SUMMARY I.D	20
TIME	20
PARAMETER I.D	7
STATISTICS	<u>28</u>
	78

e. Storage Requirements

1) Computations

- "Worst case" sizing assumes that 150 performance

parameter values arrive each second from each reporting facility:

75 PERF PARAM. PER 4800 BIT BLOCK

x2 4800 BIT BLKS IN 9.6 KB/SEC

150 P P. PER SEC.

- Thus, 150 x 9 reporting facilities = 1350 performance parameters arrive each second.
- Therefore 1350 x 10 threshold levels = 13,500 threshold comparisons must be made per second

2) Storage

- The threshold data base must contain
25 param.
x 250 threshold levels (10 values @ 25 bits/value)
x 9 reporting facilities
56,250 bit storage requirements
- Performance parameter scratch file
1,350 perf. parameters per sec.
x 60 one minute of storage
81,000
x 30 bits (perf param frame minus message ID
and time)
2,430,000 bits

5 Data Monitor

Preliminary sizing estimates for the DATA MONITOR function have been made by NASA. For the purposes of this analysis, the NASA estimates provide the information needed to proceed with the configuration and cost analysis. Therefore, sizing estimates are not provided for the DATA MONITOR herein

SECTION 3
MANPOWER COST ESTIMATES
AND COMPARISONS FOR THE
TDRSS ERA NCC

A. INTRODUCTION

This section provides manpower cost estimates for the TDRSS era NCC. Additionally, comparisons are made between the 10 year costs associated with projected NCC staffing and current NOCC staffing. NCC staffing estimates were supplied by NASA. All manpower costs identified are related to the Federal Civilian Pay Scale (General Schedule, effective 1 October 1975) as published in the May 1976 issue of Air Force magazine. No effort has been made to differentiate between NASA and contractor personnel. Therefore, no allowance for private industry loading factors (G&A, profit, etc.) is made in the figures presented. A summary of this costing analysis is given in Table I-3-1. Yearly manpower cost estimates are furnished for the years 1980 through 1990. These estimates are provided in 1976 dollars (76 T), inflated (at 6%/year) dollars (IT), and discounted dollars (DT, at 10%/year). Additionally, estimates are provided for low (L), midrange (M), and high (H) combined salary estimates. As can be seen, given the assumptions and considerations identified in the remainder of this section, the future NCC staffing is projected to save from 16.7 to 23.2 million dollars when inflation is considered.

B. ASSUMPTIONS

- 6% annual rate of inflation
- NCC staffing mix does not significantly change over the costing period (11 years)
- Future staffing mix is representative of current staffing mix
- Cost analysis period is from beginning of 1980 through 1990 (11 years).

C DETAILS OF ANALYSIS

The following describes the factors and methods utilized in developing Table 1-3-2.

1. NCC Staffing

Table 1-3-2 identifies the fundamental data used in the NCC staffing cost analysis. Positions and number of personnel occupying each position were provided by NASA. Equivalent GS grades for positions identified are NASA (as indicated by *) and BDM estimates to arrive at the total yearly salary requirement per position, the number of personnel was multiplied by the low and high extremes of the identified GS grade. Where GS grade spans are indicated, a low-low, high-high approach was used. For the lowest grade identified, the lower pay scale extreme was used for the lower salary range bound. The high bound was the highest pay scale extreme for the highest grade identified. For example, the second entry in Table 2 identifies a secretary with an equivalent GS rating of grade 4 or 5. The lowest scale for a GS-4 is \$7,976/year while the highest scale for a GS-5 is \$11,607/year. Thus, a range of \$7,976-\$11,607/year applies to the secretary. Summing the low and high values, which were rounded after multiplication of number times salary range, provides the range of yearly NCC manpower costs in 1976 dollars. The midrange value is also identified. Compound interest factors were used to derive the inflated and discounted dollar values as a function of year. Single payment, compound amount factors were used to derive inflation totals, single payment present worth factors were used to discount the inflated dollars. The results of the multiplication of these factors and the values in Table 1-3-2 provide the entries in the first half of Table 1-3-1.

2. Current Staffing

Current staffing costs were not available for this analysis. It is dubious that current operations related manpower costs would have provided a valid basis for comparison since it would reflect a mix of contractor and NASA personnel. Therefore, it was assumed that the mix of NCC personnel reflected the current mix of operations personnel and indeed was

proportional to it for cost purposes. Therefore, a factor of 160/140 or 1.1429 could be applied to the NCC estimates to determine equivalent current staffing estimates through the 1990 period.

TABLE 1-3-1

		NCC									CURRENT STAFF								
TYPE \$		76T			IT			DT			76T			IT			DT		
CAT. YR.		L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
80		2.1	2.5	2.9	2.6	3.1	3.6	1.8	2.1	2.5	3.0	3.6	4.1	3.7	4.4	5.1	2.6	3.0	3.8
81		2.1	2.5	2.9	2.8	3.3	3.8	1.7	2.0	2.4	3.0	3.6	4.1	4.0	4.7	5.4	2.4	2.9	3.4
82		2.1	2.5	2.9	2.9	3.5	4.1	1.6	2.0	2.3	3.0	3.6	4.1	4.1	5.0	5.9	2.3	2.9	3.3
83		2.1	2.5	2.9	3.1	3.7	4.3	1.6	1.9	2.2	3.0	3.1	4.1	4.4	5.3	6.1	2.3	2.7	3.1
84		2.1	2.5	2.9	3.3	3.9	4.6	1.5	1.8	2.1	3.0	3.6	4.1	4.7	5.6	6.6	2.1	2.6	3.0
85		2.1	2.5	2.9	3.5	4.2	4.9	1.5	1.8	2.1	3.0	3.6	4.1	5.0	6.0	7.0	2.1	2.6	3.0
86		2.1	2.5	2.9	3.7	4.4	5.1	1.4	1.7	2.0	3.0	3.6	4.1	5.3	6.3	7.3	2.0	2.4	2.9
87		2.1	2.5	2.9	3.9	4.7	5.4	1.4	1.6	1.9	3.0	3.6	4.1	5.6	6.7	7.7	2.0	2.3	2.7
88		2.1	2.5	2.9	4.2	5.0	5.8	1.3	1.6	1.8	3.0	3.6	4.1	6.0	7.1	8.3	1.9	2.3	2.6
89		2.1	2.5	2.9	4.4	5.3	6.1	1.3	1.5	1.8	3.0	3.6	4.1	6.3	7.6	8.7	1.9	2.1	2.6
90		2.1	2.5	2.9	4.7	5.6	6.5	1.2	1.5	1.7	3.0	3.6	4.1	6.7	8.0	9.3	1.7	2.1	2.4
TOTALS		23.1			39.1			16.3			33.0			55.8			23.3		
			27.5			46.7			19.5			39.6			66.7			27.9	
				31.9			54.2			22.8			45.1			77.4			32.8

* VALUES IN MILLIONS OF DOLLARS

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TABLE 1-3-2

<u>POSITION</u>	<u>NO.</u>	<u>EQUIV GS</u>	<u>SALARY RANGE</u>	<u>TOTAL (76 DOLLARS)</u>
NETWORK DIRECTOR	1	14*	26,861 - 34,916	27K - 35K
SECRETARY	1	4-5	7,976 - 11,607	8K - 12K
ASSIST. DIR FOR OPS	5	13*	22,906 - 29,782	114K - 149K
ASSIST. DIR FOR TECH	5	13*	22,906 - 29,782	114K - 149K
TDRSS MA	8	11*	16,255 - 21,133	130K - 169K
TDRSS SA	8	12*	19,386 - 25,200	155K - 202K
GSTDN	8	9*	13,482 - 17,523	108K - 140K
DATA MONITOR	8	12*	19,386 - 25,200	155K - 202K
ACQ/TRK	4	12*	19,386 - 25,200	78K - 101K
SIM/TEST	8	12*	19,386 - 25,200	155K - 202K
COMM CONTROL	4	11*	16,255 - 21,133	65K - 85K
SCHED/STATUS	8	11*	16,255 - 21,133	130K - 169K
TDRSS SPECIALIST	4	11-12*	16,255 - 25,200	65K - 101K
SUPPORT ANALYST	4	11-12*	16,255 - 25,200	65K - 101K
DOC/REQM'TS	3	5-6*	8,925 - 12,934	27K - 39K
MAIN/EQUIP SUPVR	1	6-7	9,946 - 14,358	10K - 14K
SUPPORT SYS SUPVR	4	6-7	9,946 - 14,358	40K - 56K
SYST TECHS	16	6-9	9,946 - 17,523	160K - 224K
CLK/DRAFTS	1	6-9	9,946 - 17,523	10K - 17K
SYST ENGRS	8	10-12	14,824 - 25,200	119K - 202K
LOGISTICS	4	5-6	8,925 - 12,934	36K - 52K
SCHED SUPP/PLN'G	3	12-13*	19,386 - 29,782	58K - 89K
HW. SUPP/PLN'G	1	12-13*	19,386 - 29,782	19K - 30K
SW SUPP/PLN'G	5	12-13*	19,386 - 29,782	95K - 150K
OPS COMM	8	5-6	8,925 - 12,934	72K - 104K
CONTRACT ADMIN	4	5-6	8,925 - 12,934	36K - 52K
CUSTODIAL ENGR	2	5-6	8,925 - 12,934	18K - 26K
TOTAL PER YEAR				2069K - 2872K
CENTER OF RANGE				2471K

*NASA GRADE ESTIMATES

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SECTION 4
COMPUTER CONFIGURATION AND
SOFTWARE COST ESTIMATES

A. INTRODUCTION

This section provides computer hardware costs for NCC ADP equipment arranged in a Star, Ring or single "medium" size configuration. Additionally software development costs are provided for the functions identified in NASA's Composite NCC Functional Flow Diagram. It should be noted that cost estimates are not provided for the "Display" or "Memory" functions. Based on the combined hardware configuration and software development costs identified in this section the medium size computer configuration for the NCC seems the most desirable. The number of man years estimated for the software development was based on the assumption that each member of the software development team was a highly experienced individual. This assumption was made to minimize the software development team size in order to ensure maximum communication among the individuals working in the components of the software package. If the preceding assumption is not valid the manyear estimates given could increase significantly.

B. CONFIGURATION 1 - STAR

Figure 1-4-1 identifies the Star configuration for this analysis.

1. Minicomputer 1

Minicomputer 1 is the applications Executive and includes system I/O. All data will be framed synched and DMA/DPM transferred. Because of the I/O required, this computer will be double buffered in common buffers. The buffer required for a 20% sample rate is 256 K words (10.22 M bits input/sec x 2 buffers ÷ 16 bits/word x 20%). Most of this data will be made known to the Data Monitor function which will process it in 1 second. The Data Base Manager task will require 12 K core and 4000 lines of code. The Action Instigator will require 8 K core and 500 lines of code. The three other tasks will require 6 K core and 600 lines of code. The operating system

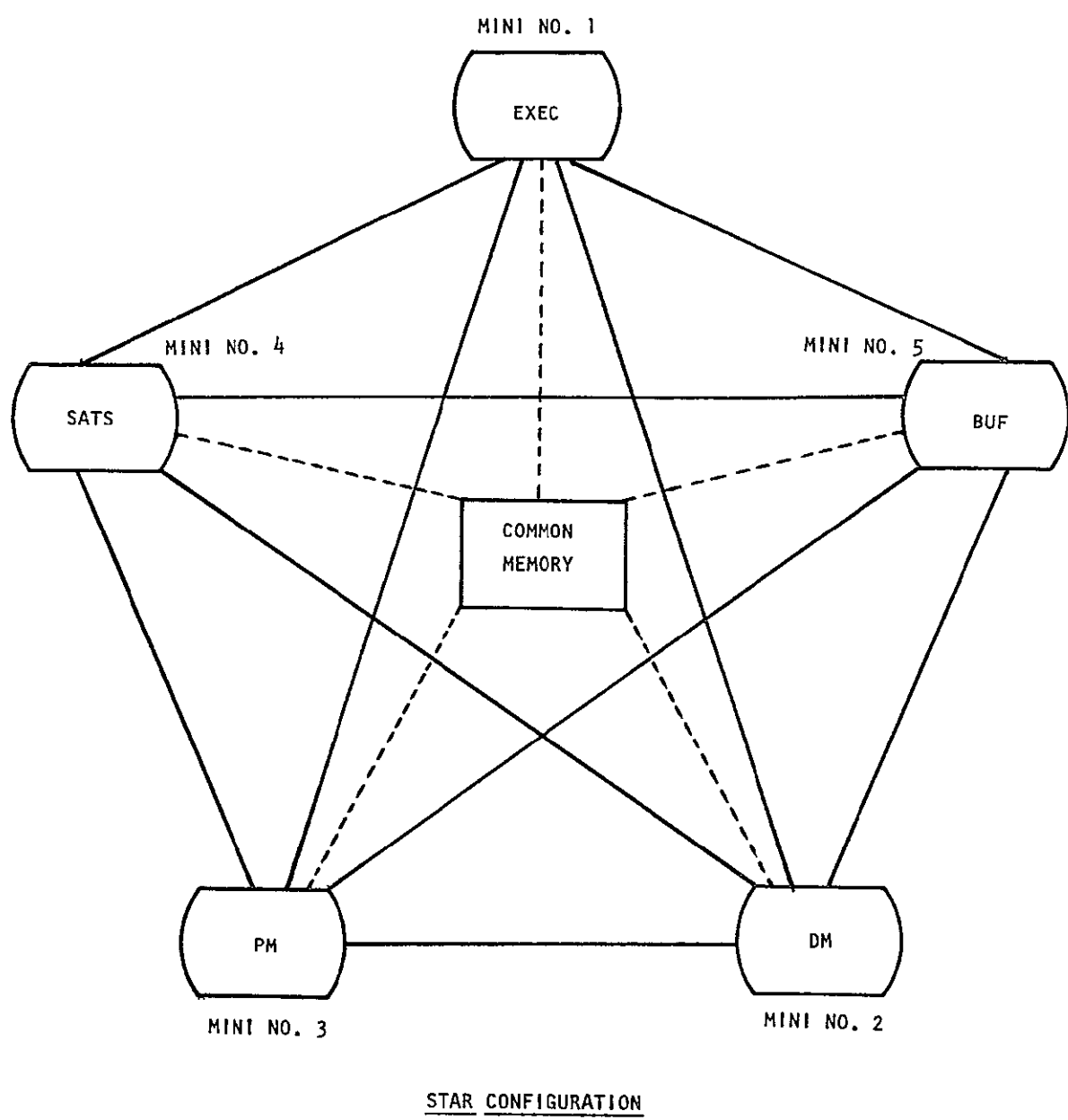


Figure I-4-1. The Star Configuration

will require 28 K core in the Executive and have 5000 lines of code. The system function will include communication to the Executive display devices.

2. Minicomputer 2

Minicomputer 2 is the Data Monitor. It must be able to process 256 K words/sec. to monitor the data, perform the data parameter evaluation and prepare the display information for the monitor display device. The buffer size required for 40 spacecraft, double buffered, will be 36,750 words ($[7000 \text{ bits/frame} \times 40 \text{ spacecraft}] \div 16 \text{ bits/word} \times 2 + 1750 \text{ words of overhead}$). Formatting and display device support could require 27,250 words of memory.

3. Minicomputer 3

Minicomputer 3 is the Performance Monitor. The Performance Monitor requires 9-9.6 KB input lines and 1-9.6 KB output line as well as display devices. Assume that 150 performance parameter values arrive each second from each reporting facility. Then 13,500 threshold comparisons must be made per second ($150 \times 9 \text{ facilities} \times 10 \text{ threshold levels}$). Processing will require 55 CPU cycles per threshold or 742,500 cycles per second. Memory required will be 10.5 K words [$75 \text{ parameters} \times 10 \text{ values} \times 25 \text{ bits/value} \times 9 \text{ facilities} \div 16 \text{ bits per word}$] for threshold data, 5 K words [$1350 \text{ performance parameter} \times 2 \text{ buffers} \times 30 \text{ bits} \div 16 \text{ bits per word}$] for scratch file and 10 K words [$9 \text{ facilities} \times 9.6 \text{ KB} \times 2 \text{ buffers} \div 16 \text{ bits/word}$] for buffer. In addition, 25 K will be required for application software and 8 K for the operating system. Total Memory required is 58 K words.

4. Minicomputer 4

Minicomputer 4 will include the Acquisition Data, Scheduling and Test/Simulation functions. Acquisition Data will require 14.1 K words memory and 37,420 CPU cycles to process 2 integrations over a flight time of one hour each. Scheduling will require 22.8 K words memory and 8,118 CPU cycles to service 2 customer requests or schedule changes. The largest number of CPU cycles is required by the verification of geometry. The test and simulation function will require 2.7 K memory and 1700 CPU cycles for a test. Input into ACQ will require 24 K for buffers. Total memory for minicomputer 4 is 64 K words. Total CPU cycles/sec is 47,238.

5. Minicomputer 5

Minicomputer 5 is an on line back-up unit that will also do schedule forecasting, software development and maintenance, and hardware T&D.

6. Configuration 1 - Summary

Configuration 1 is five identical CPUs, each able to address any other, with shared disc, tape drives, communications and some shared memory.

a. Hardware

PDP-11/70:

- (1) Manufacturer Digital Equipment Corporation
146 Main Street
Maynard, MA

(2) Configuration

- 5 1.0 μ CPU's with 64 K words of 16 bit memory and hardware floating point arithmetic
3 128 K word 16 bit memory
6 1.0 M baud communications interface
15 40 K baud communications interface
5 512 K word (1 μ /byte transfer) disc
4 800 bpi tape drives
1 132 position 64 character set, 60 lines/min printer
(3) Cost \$571,700.

b. Software

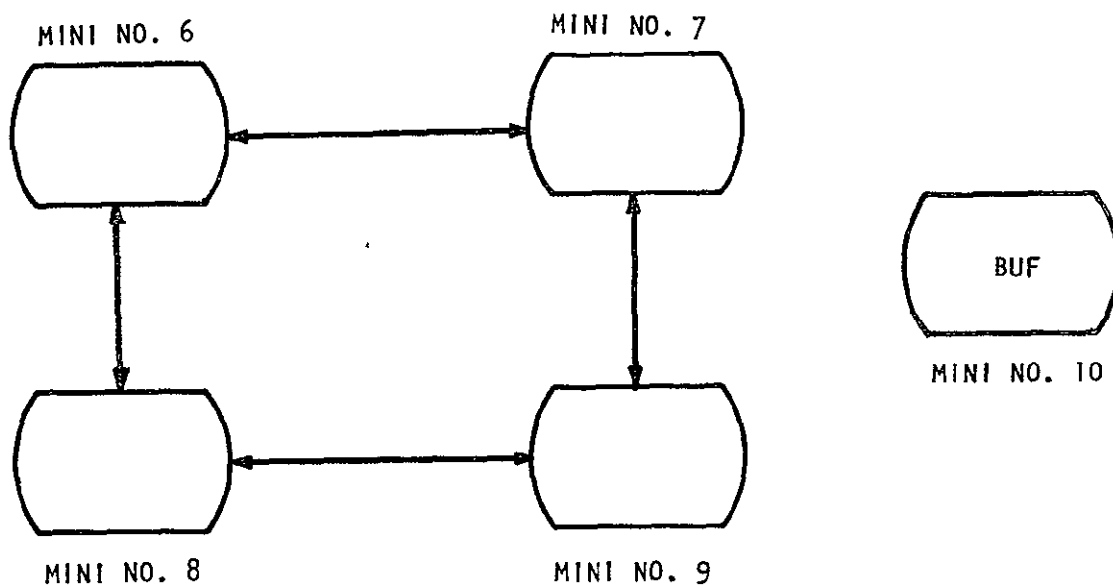
Development of the operating system to communicate between all CPUs and all communications, to roll in and out the back up CPU and the necessary I/O protocol will require 10 man years of effort. Development of applications software, taking advantage of higher order language, will require 6 man years. Total software cost is \$1,200,000.

C. CONFIGURATION 2 - RING

Figure 1-4-2 illustrates the Ring configuration for this analysis.

1. Minicomputer 6

Minicomputer 6 is similar to minicomputer 1 except that only half of the I/O will be processed by 6. The buffer requirement is 128 K memory.



RING CONFIGURATION

- 4 Equal Members
- Direct Communications to only 2
- Executive Function "Distributed"
- Data Addressing Problem
- Replacement by BUF

Figure I-4-2. The Ring Configuration

The other half of the I/O will be processed by minicomputer 7. System software will be considerably different due to the distribution of control of the CPUs and the more complex addressing scheme that will be required. Memory required is 192 K words.

2. Minicomputer 7

Minicomputer 7 is similar to minicomputer 2 except that half of the I/O will be processed by 7. The buffer requirement is increased by 128 K memory. In addition the display function has been passed to minicomputer 9. Memory required is 192 K words.

3. Minicomputer 8

Minicomputer 8 is identical to minicomputer 3 except that 8 additionally is required to support the address - through capability and to control its own disc.

4. Minicomputer 9

Minicomputer 9 is similar to minicomputer 4 but also has the display requirement added to the operating system expansion.

5. Minicomputer 10

Minicomputer 10 is the backup and forecast scheduler. The connection of 10 to replace any of 6, 7, 8 or 9 is a much more complicated task than Mini 5.

6. Configuration 2 - Summary

Configuration 2 is five identical CPU systems, each able to address 2 other CPUs directly and 1 indirectly. Nothing is shared.

a. Hardware PDP 11/70

(1) Configuration

5 1.0 μ CPUs with 192K.16 bit memory, hardware floating point arithmetic, 3 1.0M baud communications interface, 440KB communications interface, 1 512K word disc, 1 800 bpi tape drive

1 132 position 64 character set, 60 line/min. printer.

(2) Cost \$686,650.

b. Software

Development of the operating systems to communicate through intermediate CPUs, to provide for high rate CPU to CPU data transfer, to

roll in and out the backup CPU and the necessary I/O protocol will require 11.5 man years of effort. Development of application software will be complicated by the addressing requirement and the data transfer problem. Application software development will require 7 man years. Total software cost is \$1,387,500.

D. CONFIGURATION 3 - MIDI

1. Midicomputer 1

Midicomputer 1 has the functions of the Executive, Data Monitor Scheduler, and Test/Simulation. Memory required for buffer is 128K, 32 bit words. Application software will require 76K words (Executive 5K, Data Monitor 46K, Scheduler 22K and Test/Simulator 3K). Total cycles per second is 815,623. System software will require 52K words. Total memory requirement is 256K 32 bit words.

2. Midicomputer 2

Midicomputer 2 has the functions of the Acq. Data and Performance Monitor. The Performance Monitor will require 12.5K words for buffer and 25K words for application software. Acq. Data will require 12.5K words for buffer and 14.1K words of memory. Total cycles per second is 781,270. System software and display device software will require 116K words.

3. Midicomputer 3

Midicomputer 3 is an on-line backup unit that will also do schedule forecasting, software development and maintenance, and hardware T&D.

4. Configuration 3 - Summary

Configuration 3 is three midi CPUs each able to address the other two.

a. Hardware - Interdata 8/32

- (1) Manufacturer: Interdata
2 Crescent Place
Oceanport, N. J. 07757
- (2) Configuration

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- 3 750 nsec CPUs with 256K 32 bit memory and hardware floating point arithmetic
 - 3 9.6/40 KB line adapters
 - 3 Parallel communicating interface
 - 3 7 track 200/800 bpi 45 ips tape drive
 - 3 2,500,000 byte disc
 - 2 400 cpm card reader
 - 1 132 position 64 character 60 lpm printer
- (3) Cost \$411,600.

b. Software

Development of the operating system to communicate to all CPUs and accept I/O protocol will require 2 man years of effort. Development of application software will require 6 manyears. Total software cost is \$675,000.

E. ESTIMATED COST SUMMARY

Configuration	Hardware	Software	Total
1	571,700	1,200,000	1,771,700
2	686,650	1,387,500	2,074,150
3	411,600	675,000	1,086,600

F. SIZING DETAILS

FUNCTION/TASK	STORAGE BITS	MEMORY K WORDS	CPU CYCLES
<u>Exec.</u>			
I/O Controller	4×10^3	256.	768K
Data router	4×10^3	2.	150
Testing	240×10^3	2.	250
DBM	60×10^3	12.	11580
Config & Status	3×10^3	2.	880
Action Instig.	92.5×10^3	8.	1500
TOTALS	403.5×10^3	282.	782360

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	BITS	K WORDS	CYCLES
<u>ACQ DATA</u>			
Exec i/f		1.	
Avail Verf.		-	8800
Site Ackn.		.1	-
Data Veri.		3.	100
Data Reduce		2.	1920
Vector Predict (120 Δt x2)		6.	25600
Track Mon.		1.	775
Perf. Comp.		1.	225
TOTALS	2.85×10^6	14.1	37420

<u>PERFORMANCE MON.</u>			
Exec i/f		.1	(675x10 ³)
Message Process.		.5	5x1350
Line Select		.5	
Threshold Comp.		.9	10x1350
Summary Gen.		.5	18x1350
User Mess. Gen.		.5	
Out Formatter		1.0	18x1350
TOTALS	55×10^3	4	743,850

<u>Schedule</u> (2 Active Requests)			
Check id.	1×10^3	.1	18
Exec i/f	--	.1	4
Auth tree	8×10^3	4.	66
Disposition	--	.2	10
Geo verf.	700×10^3	10.	7000
Req. router	--	-	10
Forecast hopper	1×10^6	1.	-
Schedule build	425×10^3	1.5	260
Conflt res Hpr	50×10^3	1.	-
Conflt res	250×10^3	3.	560
Sched. gen	1.4×10^6	.5	50
Message form	-	1.	100
Distrib.	-	.4	40
TOTALS	3.834×10^6	22.8K	8118.

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<u>TEST/SIM</u>	BITS	K WORDS	CYCLES
Start up		.1	
Initiator	4.8×10^3	1.	100
Output Test	-	.1	50
Log results	4.8×10^3	.5	1000
Test Response	9.6×10^3	1.	550
TOTALS	19.2×10^3	2.7	1700

G. APPLICATIONS SOFTWARE

ITEM FUNC.	I/O	DISC KWDS*	BUFF. KWDS*	MEMORY KWDS*	CPU Cycles	DEVELOP. Manyears
EXEC	6x1.54M 15x56K 15x9.6K	25.2	256	26	782360	1.5
DATA MON.				46	8000	2.0
PERF. MON.	10x9.6K	4.1	60	4	743850	.5
SCHED		239.6		22.8	8118	1 0
ACQ	3x9.6K 7x56K	178.	31	14.1	37420	75
TEST SIM		.6		2.7	1700	.25

H. OPERATING SYSTEM DEVELOPMENT EFFORT (MANYEARS)

ITEM Config.	Ext. I/O	Intrl. I/O	Add'ng	CPU Control	Perif. Control	Total
STAR	2	2	2	2	2	10
RING	2.5	2	3	2	2	11.5
MIDI	1 0	-	-	1 0	-	2.

*16 BIT WORDS

SECTION 5
COMPUTER PROGRAM SPECIFICATIONS· ACQUISITION DATA

1. SCOPE

1.1 Identification

This section is a specification for the software to implement the ACQUISITION DATA function of the planned 1980 NCC

1.2 Functional Summary

ACQ DATA will provide for the monitoring of network acquisition and tracking information. This responsibility involves three operations

- a. The transmission of acquisition data to TDRSS and GSTDN ground stations.
- b. The execution of tracking performance data tests
- c. The real-time determination of orbit parameters for comparison with tracking data.

To achieve these results, ACQ DATA will perform eight basic sub-functions. Executive Interface, Availability Verification, Site Acknowledgement, Data Verification, Data Reduction, Simultaneous Vector Prediction, Tracking Monitoring, and Performance Comparison.

1.2.1 Executive Interface

The Executive Interface function will accept tracking data identification codes, acquisition state vectors, enablement messages, and alarms from the Data Router for distribution among the ACQ DATA sub-functions. Executive Interface will also implement unload/reload sequences of the ACQ DATA software.

1.2.2 Availability Verification

The Availability Verification function will monitor the availability of acquisition data identified for transmission and generate the appropriate availability or alarm messages.

1 2 3 Site Acknowledgement

The Site Acknowledgement function will respond to site acknowledgement of acquisition data transmissions with the generation of acknowledgement or alarm messages

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1.2.4 Data Verification

The Data Verification function will monitor incoming auto-tracking data for identification, construct availability messages, and generate alarms for the reception of non-scheduled data.

1.2.5 Data Reduction

The Data Reduction function will modify incoming auto-track data for tracking test comparisons with parameters generated by the Simultaneous Vector Predictor.

1.2.6 Simultaneous Vector Predictor

The Simultaneous Vector Predictor function will simultaneously generate two updated state vectors by fourth-order Runge-Kutta integration for tracking test comparisons with incoming modified auto-track data.

1 2 7 Tracking Monitor

The Tracking Monitor function will compute first and second differences between modified auto-track and predicted state vector data, compare differences with predefined tolerances, display deviations and trends, and create a statistical summary file.

1.2.8 Performance Comparison

The Performance Comparison function will accept real-time performance data, execute a parameter comparison with standard/ threshold values, display results, and create a storage file.

2. APPLICABLE DOCUMENTS

2.1 Phase I Report TDRSS Operations Control Analysis Study, BDM,
12 May 1976 (unclassified)

2 2 Phase II Report: TDRSS Operations Control Analysis Study,
BDM, 5 August 1976 (unclassified)

3. REQUIREMENTS

3.1 Major Functional Requirements

The major functional requirements placed on the ACQ DATA function are:

- a. Transmission of acquisition data to sites, and acknowledgement of data reception,
- b. Identification check and reduction of incoming auto-track data,
- c. Orbit parameter prediction and tracking data comparisons,
- d. Tracking performance parameter monitoring,
- e. Generation of files for performance parameter and tracking data tests results.

3.2 Interface Requirements

The ACQ DATA function will receive auto-track data, tracking performance data, and site acknowledgement signals from the I/O Controller. Acquisition data for sites will also be transmitted through the I/O Controller. The Executive Interface shall provide Action Instigator triggers, IRVS, enablement messages, and software status commands. A single display will depict real-time tracking test results.

3.3 Performance Requirements

3.3.1 Computer Set

It is estimated that the major facilities needed by the ACQ DATA function are as follows:

- a. Storage of 14.1K words
- b. CRT/keyboard

3.3.2 Implementation Language

Coding necessary for the Data Reduction, Simultaneous Vector Predictor, and Tracking Monitor functions will employ a higher order language.

3.3.3 Startup and Shutdown

Reconfiguration of ACQ DATA software will be directed by the Executive function through ACQ DATA's Executive Interface.

3.4 Detailed Functional Requirements

In this section, the detailed activity flow of the Data Reduction, Simultaneous Vector Predictor, and Tracking Monitor subfunctions is developed. These subfunctions represent the dominant ACQ DATA real-time activity.

3.4.1 Data Reduction

3.4.1.1 Input

The Data Reduction function will receive automatic tracking data in the Universal NASCOM tracking data format. Relevant parameters, including face-centered tracking angles (A_1, A_2), round trip light times (T) and doppler data (\underline{W}), will be isolated and retained

3.4.1.2 Processing

Data Reduction will modify the incoming state vector ($A_1, A_2, T, \underline{W}$) to one of standard Cartesian form ($\underline{X}, \dot{\underline{X}}$) of position \underline{X} and velocity $\dot{\underline{X}}$ with respect to a fixed coordinate system. Figure 1-5-1 illustrates the computational flow. A simple transformation from spherical to Cartesian coordinates determines \underline{X} , followed by a translation and rotation to a standard reference system. The Cartesian velocity vector $\dot{\underline{X}}$ is then obtained from the doppler data \underline{W} .

3.4.1.2 Output

The modified state vector ($\underline{X}, \dot{\underline{X}}$) is transmitted to the Tracking Monitor function.

3.4.2 Simultaneous Vector Predictor

3.4.2.1 Input

The Vector Predictor function accepts initial IRVs of spacecrafts transmitting auto-track data

3.4.2.2 Processing

By fourth-order Runge - Kutta integration, Vector Predictor will update spacecraft state vectors for comparisons with incoming auto-track data. The capability for the computation of two simultaneous updates will exist, as well as the ability to update forward or backward by 45 minutes. All calculations will be performed in such a manner as to allow for real-time comparisons with the auto-track data

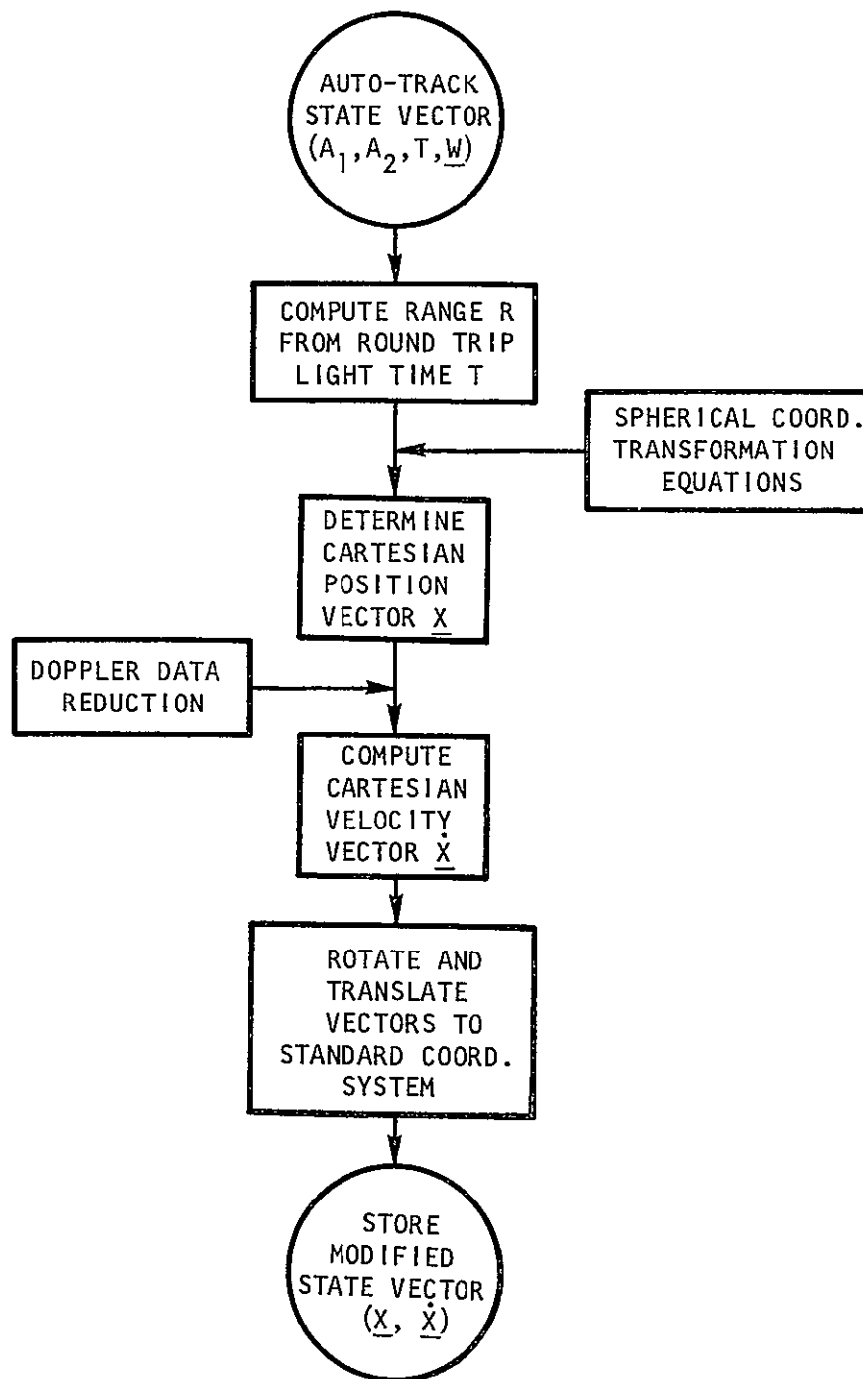


Figure 1-5-1. Data Reduction Function

Three basic computations will be performed by the Vector Predictor

- a. A determination of the integration time step h,
- b. An acceleration computation,
- c. The Runge-Kutta integration.

Figure I-5-2 indicates the flow in determination of the integration time step. The difference between the given and desired times defines the integration step, unless its absolute value exceeds a fixed default maximum, which is then assumed. For the acceleration calculation, the acceleration vector \underline{g} is given by

$$\underline{g} = \frac{-\mu \underline{X}}{R^3} \left[1 + J \frac{a^2}{R^2} \left(1 - 5 \frac{Z^2}{R^2} \right) \right]$$

and is computed from the spacecraft position \underline{X} . Parameters μ , J , and a are constants. Figure I-5-3 depicts the activity. This acceleration vector is employed in the free-flight orbiting differential equations of motion.

The orbit-determining Runge-Kutta integration accepts the initial position components X_n , initial velocity components \dot{X}_n , and integration time step h and generates the updated components of position, X_{n+1} and velocity, \dot{X}_{n+1} , based on the equations of motion $\ddot{X}_n = g(X_n, \dot{X}_n)$, by the following algorithm:

$$X_{n+1} = X_n + h \left[\dot{X}_n + \frac{1}{6} (k_1 + k_2 + k_3) \right]$$

$$\dot{X}_{n+1} = \dot{X}_n + \frac{1}{6} (k_1 + 2k_2 + 2k_3 + k_4)$$

where

$$k_1 = h g(X_n, \dot{X}_n)$$

$$k_2 = h g\left(X_n + \frac{1}{2} h, \dot{X}_n + \frac{1}{8} h k_1\right)$$

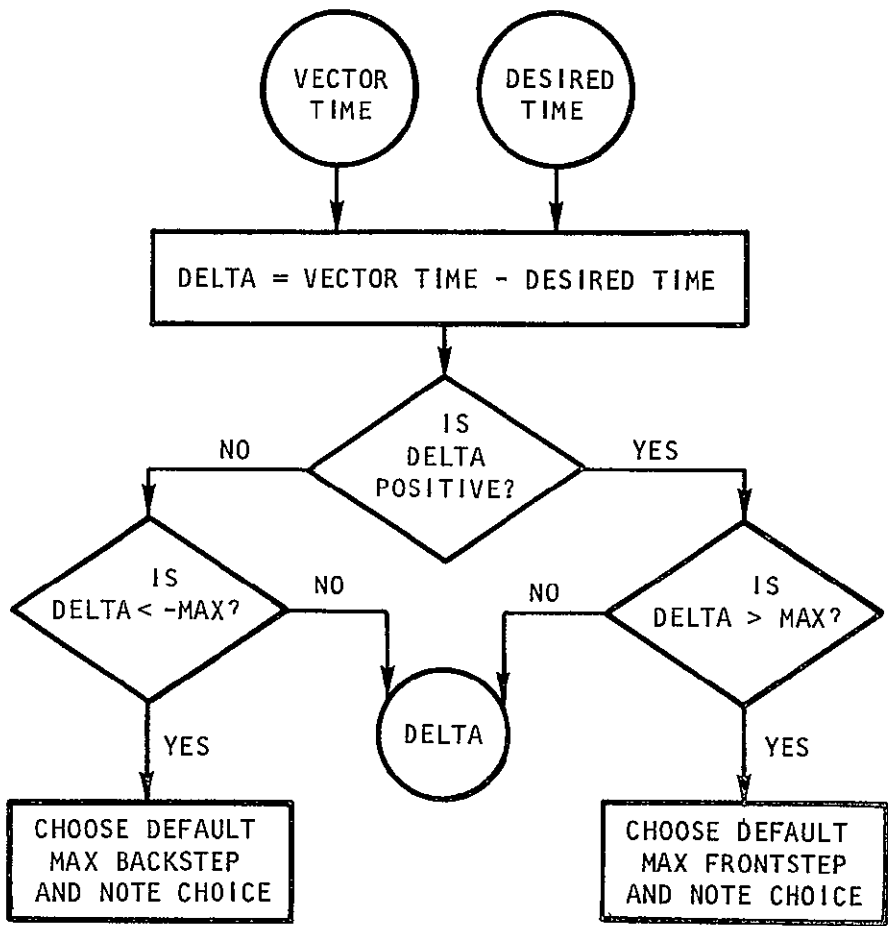


Figure 1-5-2. Integration Time Step

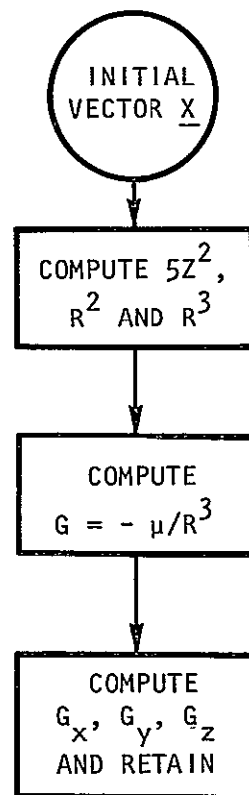


Figure 1-5-3. Acceleration Computation

$$k_3 = h g(x_n + \frac{1}{2} h, \dot{x}_n + \frac{1}{8} h k_2)$$

$$k_4 = h g(x_n + h, \dot{x}_n + \frac{1}{2} h k_3)$$

The activity flow of the Vector Predictor is shown in Figure 1-5-4.

3.4.2.3 Output

The Simultaneous Vector Predictor provides, as output, updated state vectors.

3.4.3 Tracking Monitor

3.4.3.1 Input

The Tracking Monitor function accepts updated state vectors from the Simultaneous Vector Predictor, autotrack state vectors from Data Reduction and thresholds from the data base.

3.4.3.2 Processing

The Tracking Monitor will form first and second differences between predicted and transmitted tracking position and velocity components, execute comparisons with threshold levels, and display tracking parameters. Figure 1-5-5 illustrates the flow.

3.4.3.3 Output

Tracking Monitor shall create a file for a statistical summary of tracking tests as well as display real-time tracking parameters.

4. QUALITY ASSURANCE PROVISIONS

4.1 Introduction

This section specifies the requirements for the verification of the capabilities of the ACQ DATA function to satisfy the performance and design requirements defined in section 3 above.

4.2 Levels of Testing

To ensure compliance of the ACQ DATA software with the ACQ DATA performance and design requirements, comprehensive subprogram and program

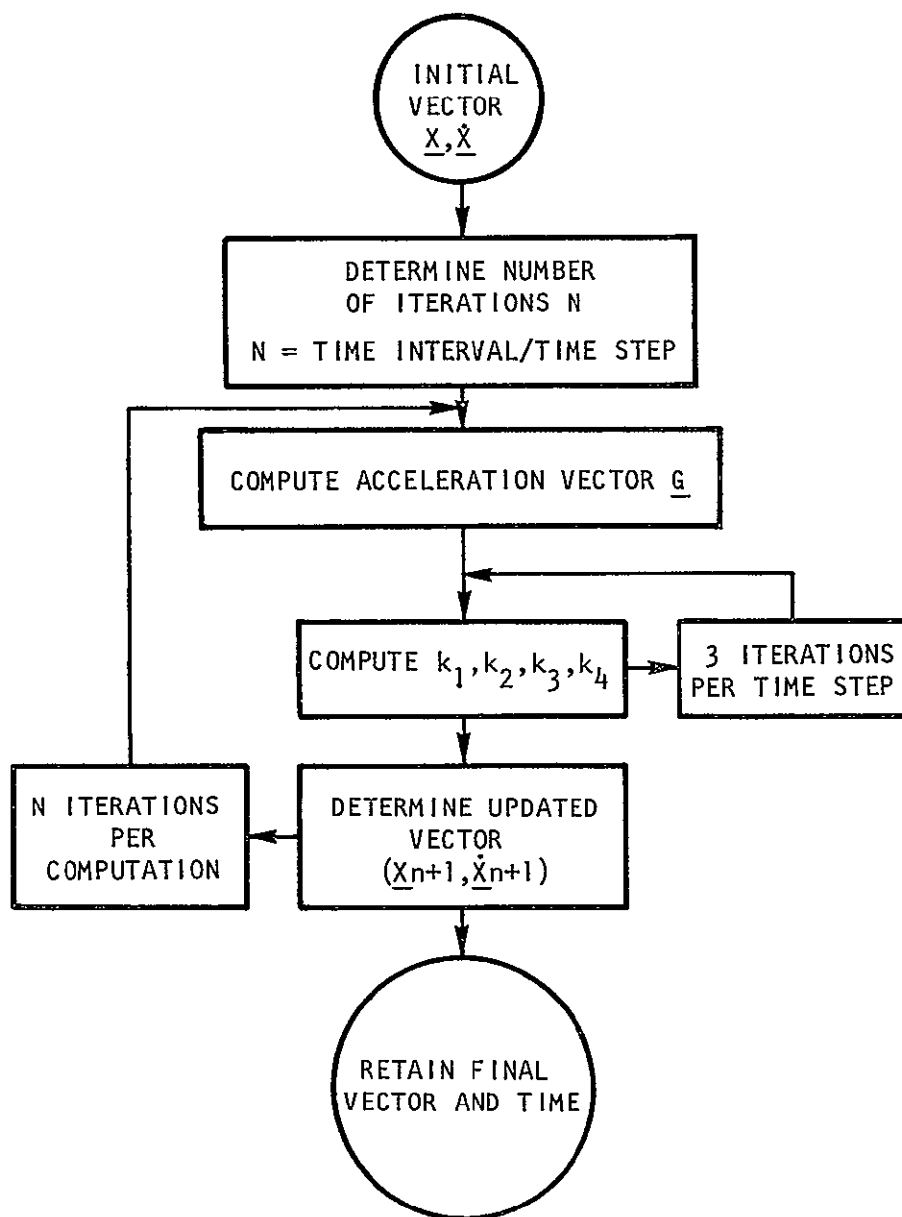


Figure 1-5-4. Runge-Kutta Integrator

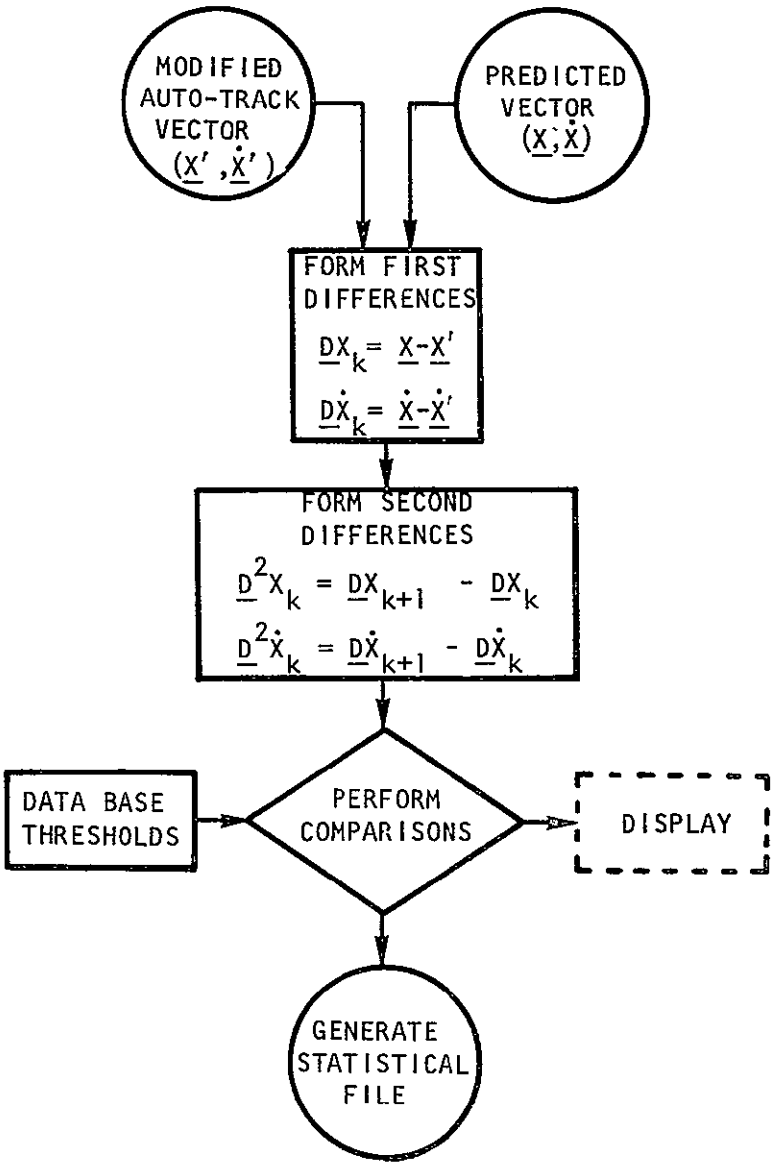


Figure 1-5-5. Tracking Monitor

testing will be performed. These tests will specifically validate the adequacy and accuracy of each of the subfunction software logic branches, computations, data handling, and internal interfaces.

4.3 Test Verification Methods

Two basic methods or techniques will be employed to verify satisfaction of performance and design requirements: inspection, and analytic verification.

Inspection consists of the direct examination of basic materials such as listings, printout formats, design specifications, and diagnostic messages. Such inspection will verify proper program execution logic flow, guarantee that programmed equations and logic agree with design flow charts, check the correctness of physical constants, and verify the adequacy and completeness of input, output, and interface parameters.

Analytic verification will insure the proper functioning of programmed logic with respect to analytic results by comparisons with exact calculations. In the case of the Simultaneous Vector Prediction function, this will be accomplished by integrating a known orbit and comparing the analytic results.

5. PREPARATION FOR DELIVERY

This section is not applicable to this specification.

6 NOTES

The glossary at the end of this specification lists the definition of the parameters contained herein.

7 ACQ DATA FILES

7.1 ACQ File 1

This file contains the acquisition data received from Code 570 which awaits transmission to sites

7 2 ACQ File 2

This file provides a statistical summary of tracking parameter tests and orbital determination comparisons.

8. GLOSSARY

A_i	Face-centered tracking radar angles, $i = 1, 2$
R	Round trip light time
\underline{W}	Doppler tracking data
\underline{X}	Cartesian spacecraft position vector
$\dot{\underline{X}}$	Cartesian spacecraft velocity vector
X_n	Cartesian spacecraft position components
\dot{X}_n	Cartesian spacecraft velocity components
$\ddot{\underline{X}}$	Cartesian spacecraft acceleration vector
\underline{G}	The gravitational acceleration field of the earth
μ	Gravitational constant
J	Oblateness term
a	Earth semi-major axis
h	Runge-Kutta integration time step
k_i	Runge-Kutta parameters $i = 1, 2, 3, 4$.
\underline{D}_X	First position difference
$\underline{D}_{\dot{X}}$	First velocity difference
\underline{D}_X^2	Second difference in position
$\underline{D}_{\dot{X}}^2$	Second difference in velocity

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SECTION 6
PERSONNEL/MACHINE REAL TIME OPERATIONS
ACQUISITION DATA

A. MAJOR FUNCTIONAL REQUIREMENTS

The subfunctional flow associated with the ACQ DATA Function is shown in Figure I-6-1. This function is responsible for three major areas transmission of acquisition data to sites, determination of spacecraft orbit parameters for real time comparison with incoming tracking data, and monitoring of tracking performance parameters.

In support of these activities a single operator at the ACQ data CRT/keyboard will oversee computer operations. Machine generated messages and displayed data will be reviewed by the operator who will formulate routine and emergency decisions, initiate appropriate interrupt-queries and redirect-commands, and generally monitor the overall ACQ Data activity flow. As a monitor, decision-maker, and re-director, the ACQ DATA Operator will form an integral element of ACQ DATA in assuring the continuous integrity and real time execution of all function requirements.

B. OPERATIONAL PROCEDURES

1. Transmission of Acquisition Data

Acquisition data containing antenna pointing angles, acquisition times, vehicle identifications, etc. will be generated by Code 570 and periodically relayed to the NCC Data Base with sufficient lead time for site transmission. Data received will be written to ACQ file 1 and reviewed by the Availability, Verification and Transmission subfunction which will verify the existence of data in file 1 necessary for scheduled acquisition events. Necessary acquisition data which is found not to be present will initiate an alarm message which will appear on the ACQ DATA

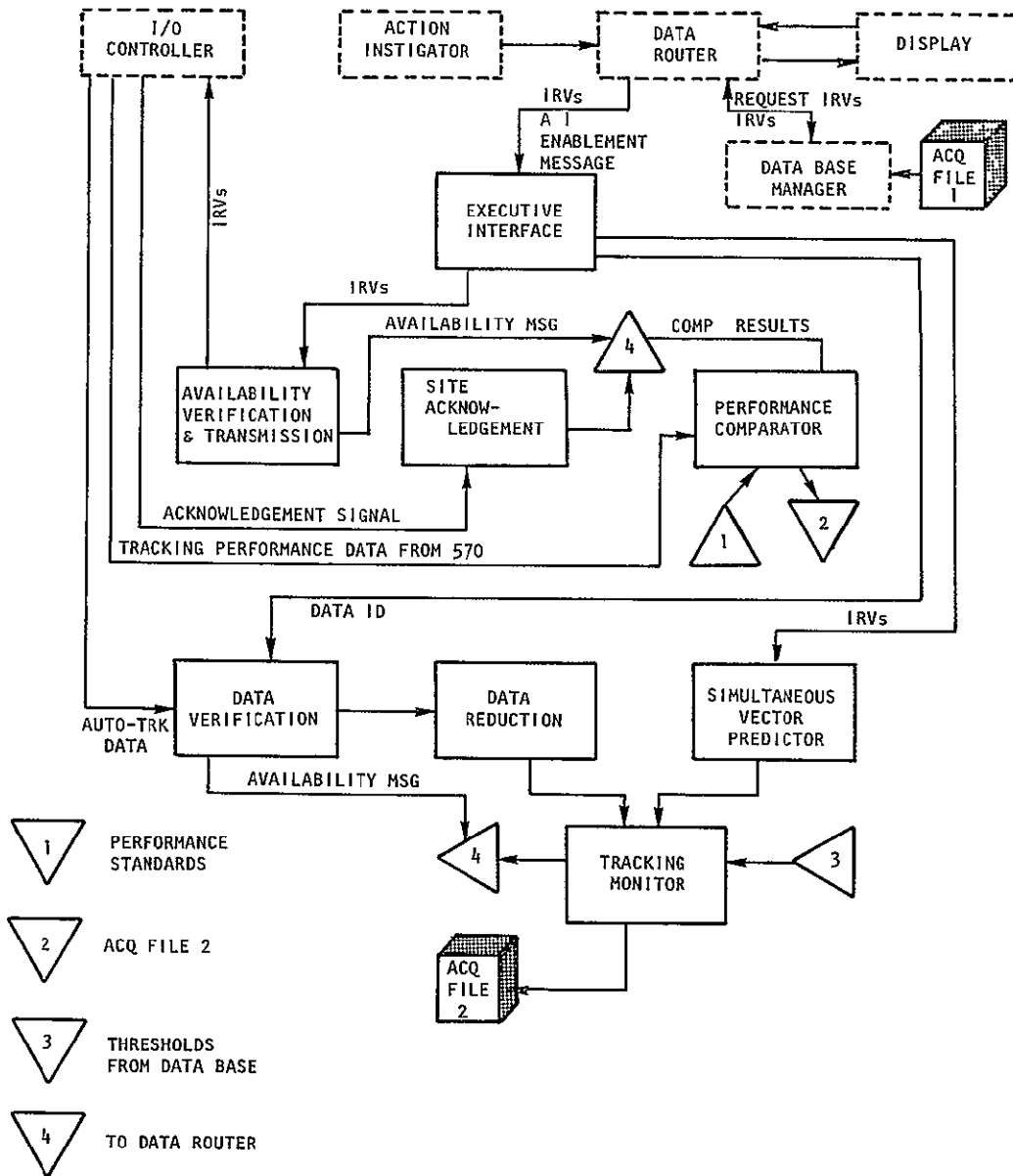


Figure I-6-1. The ACQ DATA Function

CRT display for operator intervention. If file 1 is found to be complete, batch transmission of acquisition data to sites will be executed periodically and automatically. A log of transmission events will be established for operator review upon request. The site acknowledgement function will notify display of an absence of necessary data on site, whereas properly received data will be so logged for operator inspection.

Emergencies affecting the transmission of acquisition data will be characterized as either low or high priority. Low priority emergencies include "unavailable data" and "site reception failure" alarms generated by the respective subfunctions of Availability and Site Acknowledgement. These potential alarms will occur during routine attempts at data transmission and will appear with a low-priority label on the CRT for operator action. However, because of the sufficient lead time between routine data transmission and actual spacecraft acquisition, the operator may not be required to suspend current activity for alarm consideration but may defer action to a later time. If action is deferred, a required action time interval will be defined such that a failure to dispose of the low-priority alarm within the interval will result in a repeat of the same alarm on a high-priority level for immediate operator intervention. In general, low-priority alarms will be resolved by operator interaction with Status Monitor and Executive, through the ACQ DATA CRT/keyboard, in order to request additional acquisition data and/or ascertain site status.

A high-priority alarm will require immediate real time operator consideration and consequent suspension of current activity. High-priority alarms include

- (1) determination and transmission of acquisition data for recently rescheduled or emergency-condition spacecraft, and
- (2) low-priority alarms which have not been resolved.

For a type (1) alarm, the operator will 'clear' ACQ DATA by writing any incoming tracking data to storage, suspending the computation of orbital parameters, and holding any data transmissions. An operator

request for the latest emergency spacecraft IRV will be made which will act as input to the Vector Predictor function for a determination of acquisition parameters. The computed updated IRV will then be transmitted and normal ACQ DATA operations will resume.

a. Summary of Machine Functions:

- (1) write acquisition data from code 570 to ACQ File 1
- (2) verify the availability of data necessary for scheduled events
- (3) transmit acquisition data in batches to sites at fixed periodic intervals
- (4) generate short-term site acknowledgement and data availability logs
- (5) initiate alarms to the ACQ DATA display for required data not available, or failure at site to receive transmitted data

b. Summary of Operator Functions:

- (1) during low levels of activity enter keyboard commands to request data transmission and acknowledgement logs for inspection
- (2) initiate commands in response to low-priority "unavailable data" and "site reception failure" alarms
- (3) 'clear' the ACQ DATA function for real time high-priority emergencies, and direct emergency resolution

2. Orbit-Comparison Tracking Tests

The highest level of ACQ DATA activity will be dedicated to the determination of spacecraft orbit parameters by Runge-Kutta integration and a real time comparison of these determinations with incoming auto-track data.

The identification of incoming data will be made by the Data Verification subfunction which will generate an alarm to the CRT only upon detection of unexpected data. Operator alarm response will include a notification to the Executive as well as a request for the appropriate IRV for integration. Data properly verified will be modified by the Data Reduction subfunction and compared to parameters predicted by the Simultaneous Vector Predictor in the Tracking Monitor. This latter subfunction will

execute comparisons, generate a statistical summary file (ACQ File 2), initiate "exceeding threshold" alarms, and format both the data and comparison results for CRT display.

In the routine mode of operation, the operator will monitor the tracking test displays for consistency, trends and deviations. Alarms, however, will require the operator to suspend and store the display, dispose of the alarm, then request display playback. The operator may also interrupt routine activities for the purposes of

- (1) display suspension
- (2) notification to the EXEC of sub-threshold trend variations
- (3) request of partial file 2 display
- (4) format problems, etc.

a. Summary of Machine Functions.

- (1) verify incoming ID of auto-truck data and reduce to standard form.
- (2) perform a fourth-order Runge-Kutta integration for orbit parameter determination
- (3) compare auto-track and predicted data
- (4) generate statistical summary file and display format
- (5) initiate "exceeding threshold" and "invalid data ID" alarms

b. Summary of Operator Functions

- (1) monitor tracking data and comparison results for trends, deviations, formats, etc.
- (2) respond to function alarms by writing current display to storage then requesting re-display (after alarm response) for continued monitoring
- (3) initiate commands based on monitoring decisions to reassign thresholds, request inspection of the statistical test summary file, etc.

3. Tracking Performance Parameters

Tracking performance parameters received from Code 570 will be formatted and displayed for operator inspection. Operator and machine monitoring of these parameters will parallel the procedures outlined in 2 above.

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SECTION 7
MESSAGE SIZING AND DATA RATE REQUIREMENTS

A. INTRODUCTION

This section provides an analysis of message sizing and data rate requirements for communications between the NCC and external STDN elements. The purpose is to provide block sizing tradeoffs and evaluate the capability of projected line data rates to satisfy the expected information flow. Particular emphasis is placed on the NCC-TDRSS communications. The messages, and their approximate sizes, which comprise the majority of communications identified to date are listed below, based on information provided in the "Performance Specification for Telecommunications Services via the Tracking and Data Relay Satellite System," (Reference 40) pages 52-63.

B. MESSAGE SIZES

Each of the messages identified in reference 40 was examined and generic parameter classifications developed. Each of these parameters was then allocated a raw bit size based on the number of parameter occurrences, its expected range and accuracy requirements and other special information requirements. These raw bit requirements were then mapped into 16 bit words. This 16 bit word size was assumed to be that used in the NCC computers. Hence all parameters were assumed to be stored in multiples of 16 bits. Thus, parameters creating requirements for fractional portions of a 16 bit word were mapped in whole words. It is implicit in this methodology that a requirement to "pack" parameters in some optimum manner within 16 bit words does not exist. Table I-7-1 identifies the generic parameters associated with each message in reference 40 and the associated raw bit and 16 bit word sizes.

1. NCC Administrative Message Sizing

The NCC outgoing messages identified in reference 40 are:

- (1) Scheduling Data
- (2) Operations Control Messages
- (3) Acquisition Messages
- (4) Ground Commands.

The Scheduling Data size requirements are summarized in Table I-7-2. Under the assumption of 1000 contacts per day, the analysis shows that a 24 hour schedule would consist of approximately 9×10^4 words, and a weekly schedule to be on the order of 6.3×10^5 words.

The Operations Control Messages, Acquisition Message, and Ground Commands are summarized in Tables I-7-3, I-7-4, and I-7-5, respectively. Operations Control Messages and Ground Commands were found to be short (100 words and 30 words), while the Acquisition Message, to be transmitted up to three times per day in special situations, consists of 1350 words.

The NCC incoming messages identified in reference 40 are.

- (1) Acquisition Data (from ODF)
- (2) Schedule Requests (from POCCs/USERS)
- (3) Tracking Service Data
- (4) Operations Control Messages
- (5) TDRSS Service Level Status
- (6) SA Operations Data
- (7) MA Operations Data
- (8) Performance Data.

The Acquisition Data, from the Orbit Determination Facility (ODF), should consist of a 1350 word message, similar to that described in Table I-7-4. Scheduling Requests will consist of up to 90 words, the parameters of which are summarized in Table I-7-2.

Tracking Service Data will be supplied by TDRSS. Allocation for the tracking data allows for two tracking points for each of two spacecraft to yield a 120 word message, as shown in Table I-7-6. TDRSS Operations Control and Service Level Status Messages, as shown in Tables I-7-7 and I-7-8, are each approximately 21 words in length. Table I-7-9 shows sizing for

Operations Data for TDRSS SA and MA links. These operations messages are on the order of 75 words for SA and 50 words for MA. The performance data message was assumed to consist of approximately 10 words per parameter, for ten parameters. Thus, Table 1-7-10 shows a 100 word performance parameter message for each channel. Table 1-7-11 provides a message sizing summary, for all messages delineated above, where requirements are given in 16 bit words. Also, an indication of its time sensitivity accompanies each message set.

2. Standard Block Size

As can be seen in the message summary, sizes are either very large (1,350, 90,000, or 630,000 words for infrequent messages) or routinely 120 words or less. The impact this has on determining a standard block size is simply that the block will be used inefficiently for those short messages if significantly more than 120 words are employed (exclusive of overhead). A reasonable block size, then, accounting for 14 words of NASCOM overhead would be 130-150 words. Further considerations support the choice of the 150 word block. Figure 1-7-1 is a plot of block size vs. the number of information words transmitted per second at a 9.6 kb/s rate. The graph illustrates the significant impact of 14 words of overhead on block sizes of 100 words or less since a lower percentage of the transmission is actual information. For example, using 50 word blocks, of the 600 words per second transmitted, 168 of them would be overhead. The curve flattens out for block lengths of 150 to 300 words (present NASCOM standard). The second plot, Figure 1-7-2, presents the time required to transmit the schedule, for various data rates, vs. block size. The curve presents pure transmission time, exclusive of handshaking, error control, or other communications protocol. Again, no serious degradation occurs after a block length of 150 words. Therefore, with these considerations established, a reasonable standard block size for NCC traffic is in the neighborhood of 150 words, or 2400 bits.

C. DATA RATE REQUIREMENT

The messages involved in the network control communications are all of a time sensitive nature, some more so than others. For example, the incoming tracking data and performance data have been assumed to arrive at a rate of once per second. Assuming that each requires one message block, at the 9.6 kb/s rate, tracking data and performance data will use 100% of the TDRSS to NCC line capacity if present standard 4800 bit blocks are used. If the recommended 2400 bit blocks are used, the data will utilize 50% of the line capability. Either case may cause difficulties in the routine transmission of other data to the NCC. Thus, it appears that the requirement of one sample per second for tracking and performance data make a serious case for a higher data rate line. With a 56 kb/s line, twenty-three 2400 bit blocks may be transmitted each second, with performance and tracking data requiring only 8.7% (approximately 17% using standard 4800 bit blocks). The outgoing NCC data present a different type of problem. Messages are commonly much larger and less frequent, e.g., the 630 thousand word weekly schedule, requiring substantial periods of transmission time. The comparative transmission times for transmitting the schedule at 9.6, 19.2, and 56 kb/s were illustrated in Figure 1-7-2. Using 4800 bit blocks, the schedule requires almost 20 minutes of pure transmission time, at the 9.6 kb/s rate.

D. ALTERNATIVE TRANSMISSION SCHEMES

Given the message transmission requirements as previously stated, several alternatives exist for achieving higher transmission rates. Among them are

- (1) Doubling the 9.6 kb/s line capacity
- (2) Upgrading the 9.6 kb/s rate to 56 kb/s.

Various methods of implementation exist for each of these alternatives

1. Doubling the 9.6 kb/s Line Capacity

Figure 1-7-2 illustrates the time saved in transmitting the schedule at an effective 19.2 kb/s rate. Doubling the data rate has the obvious effect of reducing by 50% the time required to transmit the long NCC outgoing messages. Performance and tracking data would require 50% of incoming capability with standard 4800 bit blocks, and 25% using 2400 bit blocks.

The actual implementation of a 19.2 kb/s data rate could be accomplished by adding another 9.6 kb/s line, establishing a virtual 19.2 kb/s link, or by replacing the 9.6 kb/s line with a 19.2 kb/s line. The monthly recurring cost for two 9.6 kb/s lines from the NCC to TDRSS is approximately \$4,570. (Reference 41).

2. Upgrading the 9.6 kb/s Rate to 56 kb/s

The impacts of a 56 kb/s rate on the NCC incoming and outgoing message requirements has been discussed above. In addition to providing the necessary data rate to support requirements, the 56 kb/s rate has the further advantage of standardizing data rates for the NCC administrative message requirements. Since every GSTDN station has a 56 kb/s capability, the data rate would be STDN-wide compatible.

At approximately four times the 9.6 kb/s monthly rental rate -- \$9,215/mo. (Reference 41) -- a 56 kb/s link could be established from the NCC to TDRSS. However, an alternative implementation technique exists. An effective 56 kb/s rate could be obtained utilizing the composite 1.544 Mb/s line. The NCC could transmit and receive messages at a 56 kb/s rate over the composite line. Since this link will be established, cost incumbrances for an additional 9.6 kb/s line to provide a virtual 19.2 kb/s link, or a 19.2 kb/s channel to replace the 9.6 kb/s line, or a 56 kb/s service to replace the 9.6 kb/s line would not be incurred.

TABLE I-7-1. GENERIC MESSAGE PARAMETER SIZE REQUIREMENTS

<u>PARAMETER</u>	<u>BIT REQUIREMENT</u>	<u>WORD REQUIREMENT</u>
ID's	16	1
TIME		
- MONTH, DAY,	14	1
- HOUR, SEC	11	1
- MICROSEC (NANOSEC.)	24	2
ANGLES	32	2
FREQUENCIES		
RESOLVED TO 100 HZ	32	2
RESOLVED TO 10 HZ	32	2
DATA RATES	32	2

TABLE I-7-2. SCHEDULING DATA MESSAGES

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	5
B. Forward Link Services	16
C. Return Link Services	39
D. Tracking Services	10
E. Simulation Services	20
F. Verification Services	
	<hr/> 90 Words Per Event
24 Hour Scheduling Message	90 Words/Event <u>x1000</u> Events/Day 90000 Word Message
Weekly Scheduling Message	24 Hr Sched. Msg <u>x 7</u> 630000 Word Message

TABLE 1-7-3. OPERATIONS CONTROL MESSAGES

<u>Types/Parameter</u>	<u>Words Allocated</u>
Messages Range From	100
Simple Requests	
(Approx 4 Words) To	
S/C State Vectors	
(Approx 25 Words)	
100 Words Should Be	
Enough To Handle These	
	100 Word Message

TABLE 1-7-4. ACQUISITION MESSAGES

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	5
B. Month, Day, Orbit No.	3
C. Position Vectors & Checksum	10
D. Velocity Vectors & Checksum	7
E. Vector Time	<u>2</u>
	27 Words Per Spacecraft
Total Acquisition Message	27 Words/Spacecraft
	x <u>50</u> Spacecraft
	1350 Word Message

TABLE 1-7-5. GROUND COMMANDS

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	5
B. Request	1-24
Service Level Status Data	_____
Reacquisition	30 Word Message
Forward Link Sweep	
User Reconfiguration	
Doppler Comp. Inhibit	
Return Channel Time	
Delay Measurement	

TABLE I-7-6. TRACKING SERVICE DATA

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	3
B. User I.D.	1
C. Service Type	1
D. Service Link I.D.	1
E. Time Tag	4
F. Ground Antenna Angle #1	2
G. Ground Antenna Angle #2	2
H. Range	3
I. Doppler Count	3
J. Reference Frequency	<u>2</u>
	22 Words
Tracking Message	30 Words Per Track Point (22 + 8 Spare)
	x 2 Points Per Track Message
	<u>x 2</u> Allocation For Two Simultaneous Tracks
	120 Word Message

TABLE 1-7-7. OPERATIONS CONTROL MESSAGE

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	5
B. Schedule Receipt	2
C. Return Channel Time Delay	3
D. Preventative Maint. Downtime Req.	3
E. Special Req.	5
F. Results of Verif. Services	<u>5</u>
	21 Words

TABLE 1-7-8. TDRSS SERVICE LEVEL STATUS

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	9
B. Status	<u>12</u>
	21 Words

TABLE I-7-9. SA AND MA OPERATIONS DATA

<u>Type/Parameter</u>	<u>Words Allocated</u>	
	SA OPS DATA	MA OPS DATA
A. General	7	7
B. Forward Links	25	15
C. Return Links	<u>40</u>	<u>25</u>
	~ 75 Word Message	~ 50 Word Message

TABLE I-7-10. PERFORMANCE DATA

<u>Type/Parameter</u>	<u>Words Allocated</u>
A. General	5
B. Perf. Type	1
C. Perf. Data	<u>4</u>
	10 Words
Performance Message	10 Words/Perf
	<u>x10</u> Perfs
	100 Word Message
	- For Each Channel

TABLE 1-7-11. MESSAGE SIZING SUMMARY

<u>MESSAGE</u>	<u>SIZE</u>	<u>TIME SENSITIVITY</u>
Outgoing:		
Daily Schedule	90000	Once Per Day
Weekly Schedule	630000	Once Per Week
Ops. Control	100	Situation Dependent
Acq. Message	1350	3 Times Daily To Twice Weekly
Acq. Emergency	27	Situation Dependent
Ground Commands	30	Situation Dependent
Incoming:		
Acq. Data	1350	Weekly
Acq. Emergency	27	Situation Dependent
Schedule Request	90	Situation Dependent
Tracking Data	120	Once Per Second
Ops Control	25	As required
TDRSS Status	21	As required
SA Ops Data	75	As required
MA Ops Data	50	As required
Perf. Data	100	Once Per Second Per Channel

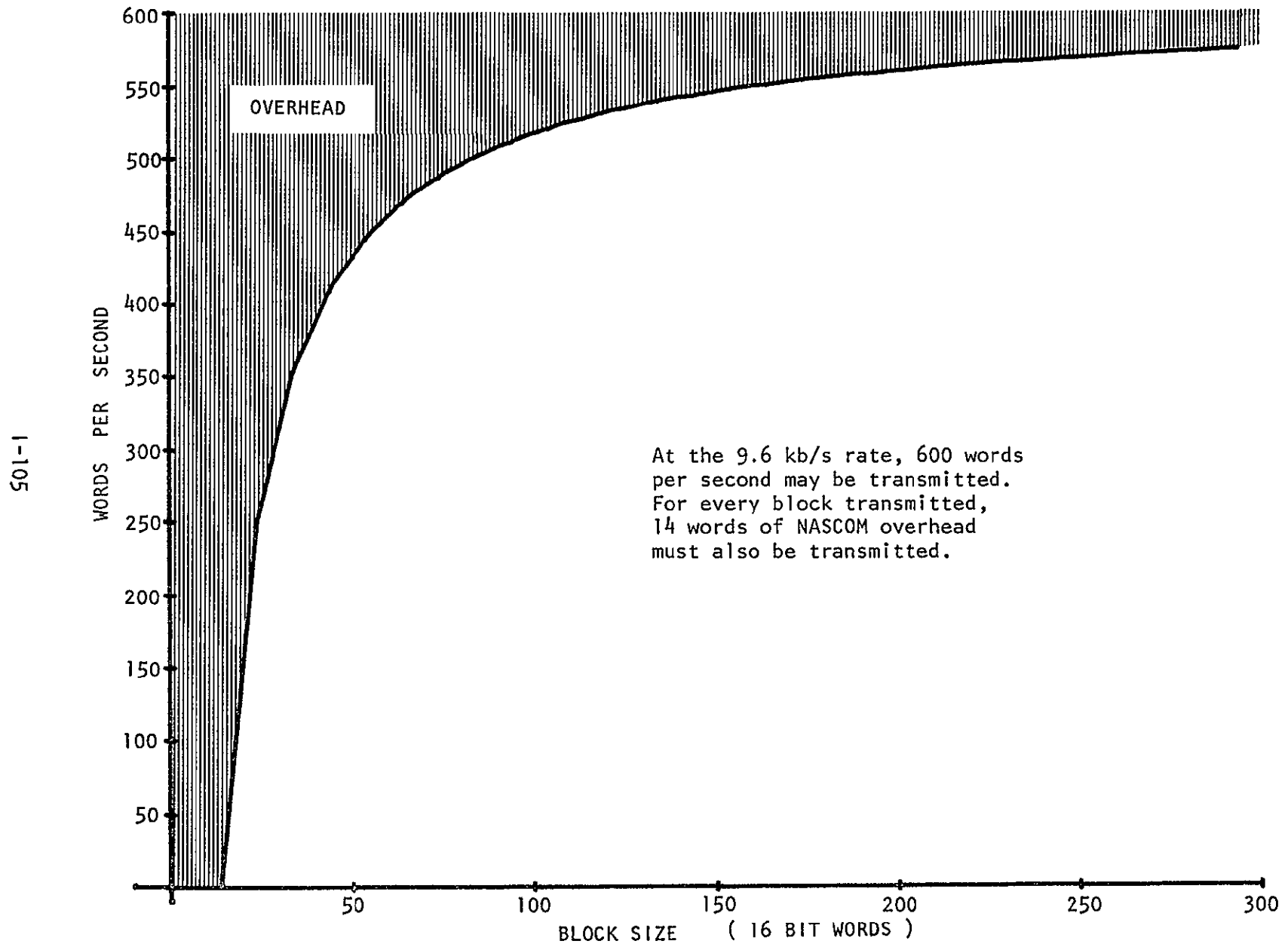


Figure 1-7-1. The Amount of Information Data Transmitted for Various Block Sizes, at a 9.6 kb/s Rate.

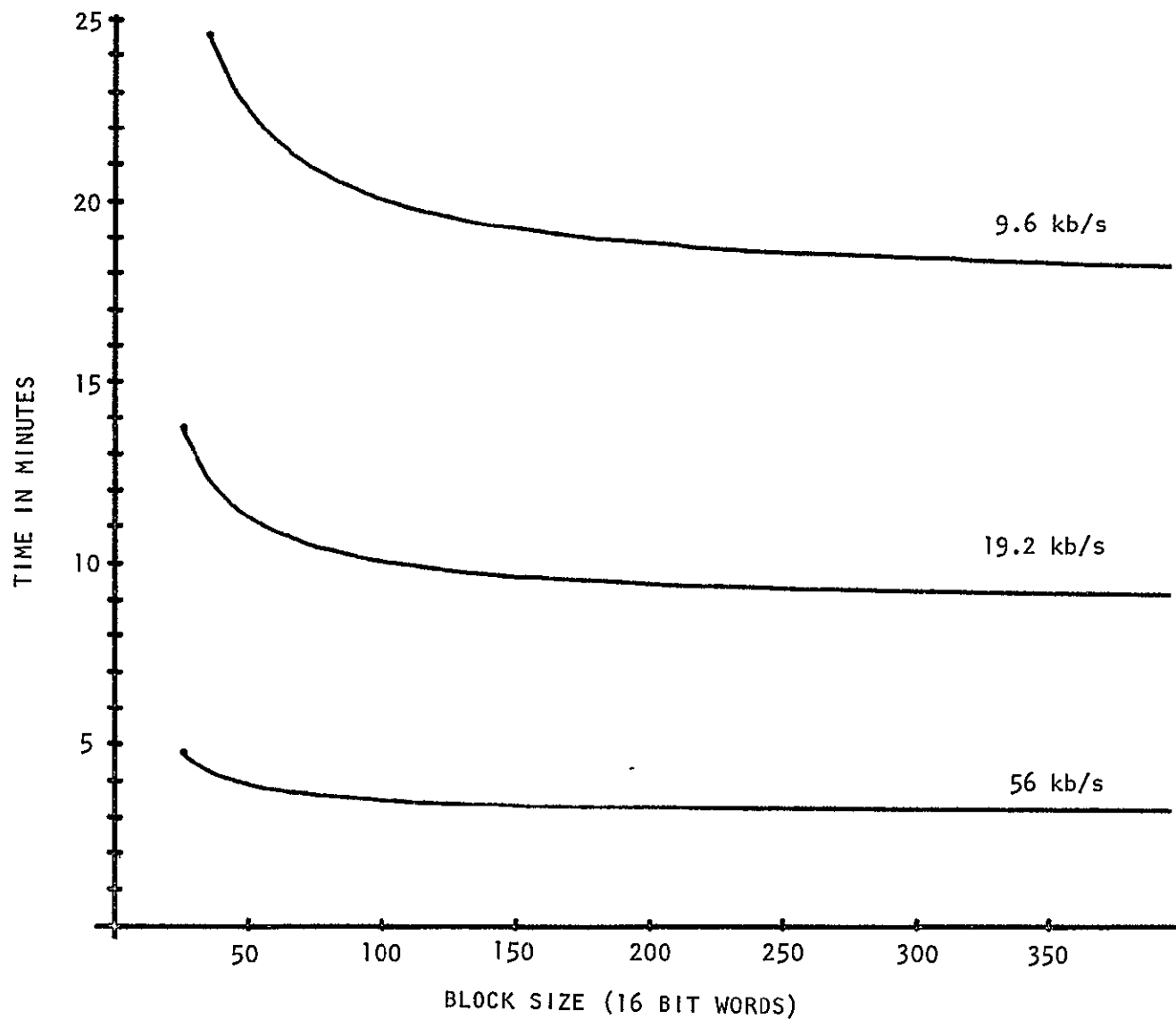


Figure 1-7-2. Time Required to Transmit a 6.3×10^5 Word Weekly Schedule.

SECTION 8
NCC CONTROLLER MANPOWER REQUIREMENTS

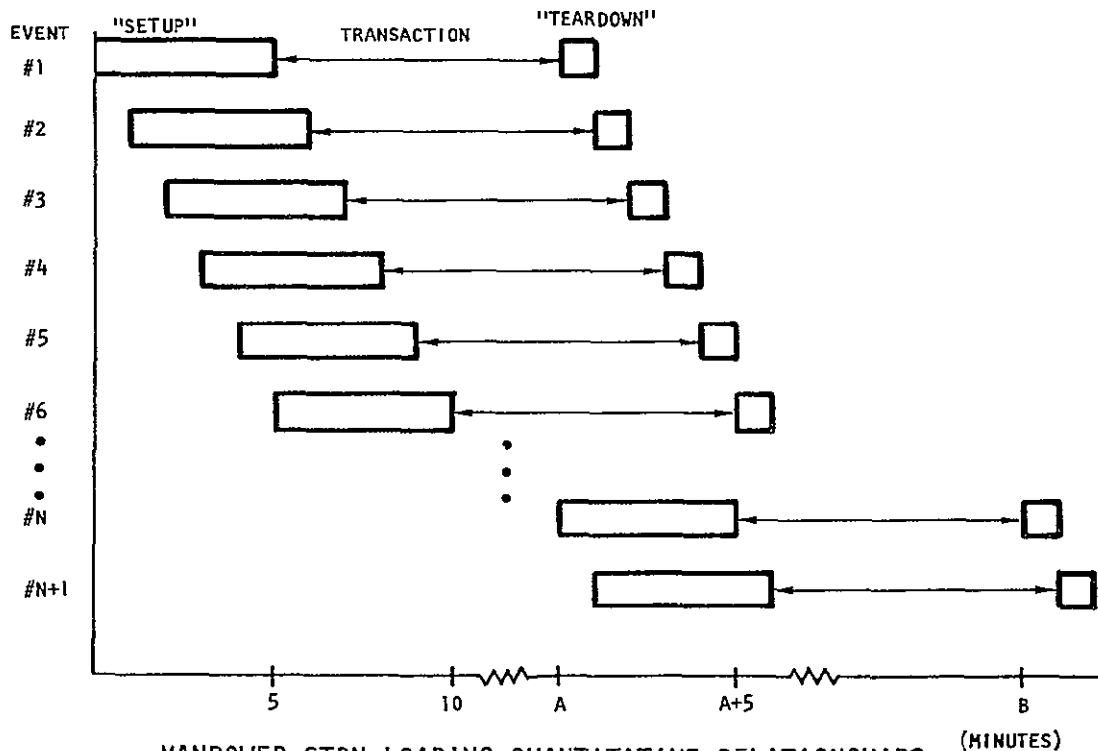
A INTRODUCTION

This section documents analyses conducted to refine the estimated Network Control Center (NCC) manpower requirements developed in Phase II. The objective of these analyses was to identify the NCC manpower required to perform operations control system activities which are directly related to, or driven by, the STDN load. The NCC position requirements directly affected by network loading are the TDRSS MA, TDRSS SA and GSTDN controller positions. The generic activities conducted at these positions which directly affect personnel requirements are "network setup" and "network teardown." Setup is the process whereby the controller insures that all network resources required to conduct a contact are available, capable and ready to support the contact. Teardown is the process whereby the controller returns all resources committed to supporting a contact to the network resource "pool" at contact completion. The speed with which the controller can accomplish these tasks will affect the probability that a second or subsequent event will occur during the critical sequence of network assembly/disassembly. Speed dictates the duration of cognizant time the network operator must give to that particular event. Once the transaction begins, however, the controller has little responsibility until completion, at which time teardown of the system must be accomplished. Coupled with speed is the rate of event arrival in determining simultaneous events. The faster the arrival rate, the greater the probability of simultaneous events.

B PHASE II ANALYSIS

Figure I-8-1 highlights the results of the manpower requirements developed in Phase II. The effects of setup and teardown activities in

DERIVATION OF SIMULTANEOUS EVENTS



MANPOWER-STDN LOADING QUANTITATIVE RELATIONSHIPS

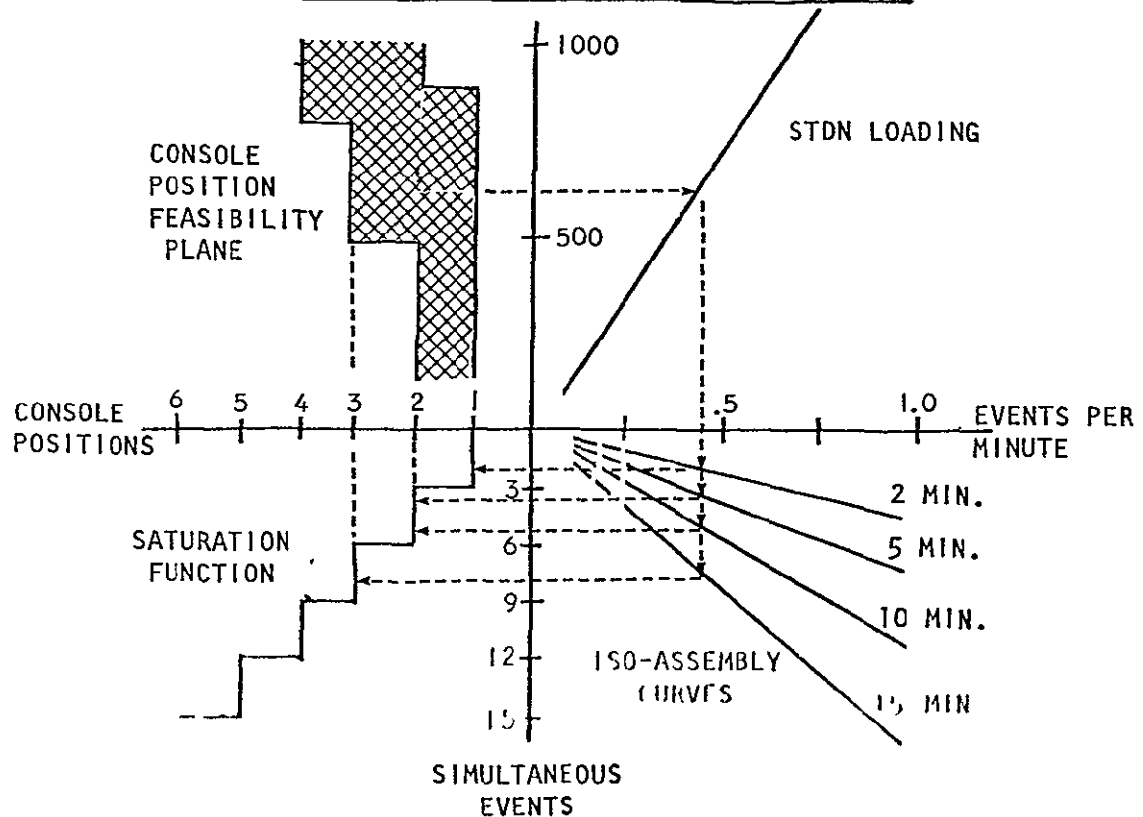


Figure I-8-1. Phase II Manpower Requirements Analysis

producing simultaneous events for controllers to manage is shown in the upper portion of the figure. The method of counting utilized in this approach always yields a maximum number of simultaneous events, in this case eight for a 5 minute setup and 1 minute teardown (See page III-72 of this report.)

The lower portion of Figure I-8-1 depicts the quantitative relationships between STDN scheduled event occurrences (i.e., spacecraft contacts), setup/teardown time requirements, human simultaneous event management capability and resultant controller position requirements. The first quadrant, STDN LOADING, represents the relationship between contacts per day, or system load, and events per minute for STDN. It was assumed that events occur in a uniform manner. Thus, in the baseline case of 620 contacts per day, events arrive at the constant rate of 0.43 per minute.

The ISO-ASSEMBLY CURVES of the second quadrant are established by associating with each event an interval representing the network assembly/disassembly time, then identifying the maximum number of simultaneous setup/teardown operations. Thus, the baseline case defines a maximum of 3.3 simultaneous events for a 5 minute assembly time and 1 minute teardown time.

This number of simultaneous events is then translated into manpower requirements by the SATURATION FUNCTION of the third quadrant. Here, each operator is assumed able to dispose of at most three simultaneous events with equal proficiency. It is also assumed that four or more events totally overload the controller's capability to manage the simultaneous events. Baseline loading, therefore, requires two operators. Additionally, interpretation of the information provided in the second and third quadrants assumes that controller personnel can manage TDRSS MA, TDRSS SA or GSTDN related events equally well. This tacitly implied that whenever any controller activity (setup or teardown) is required, any unsaturated controller could manage it with equal competence.

Finally, the fourth quadrant illustrates the CONSOLE POSITION FEASIBILITY PLANE. This plane summarizes the results obtained by the use of quadrants two and three, and allows one to pass directly from quadrant one to quadrant four in determining manpower requirements for a given load. For example, at baseline loading (quadrant one), a minimum of one and a maximum of three operators would be required (quadrant four), whereas at twice baseline these requirements become, respectively, two and four

In summary, the Phase II analysis estimates total MA, SA, and GSTDN manpower to lie between one and four console positions. These results are based upon the assumptions of

- (1) A uniform event arrival rate,
- (2) An identification of maximum numbers of simultaneous events occurring, and
- (3) A combined MA, SA, and GSTDN loading.
- (4) The ability of each controller to manage TDRSS MA, TDRSS SA or GSTDN activities.

Further refinement of the above Phase II results requires an extension of assumptions (1) and (2), and a separation of the MA, SA, and GSTDN requirements in assumption (3) and (4)

C ANALYTIC APPROACH

In this analysis it was assumed that each controller position required individuals with different skill levels and/or capabilities. Thus personnel requirements are developed independently for TDRSS MA, TDRSS SA and GSTDN. Analysis of these requirements included an identification of the average, maximum, and most frequent number of simultaneous events per minute as a function of load and total setup/teardown times.

Central to this investigation was the generation of event schedules based on projected STDN support requirements. The Conflict Analyzer algorithm developed during Phase I was utilized to obtain a statistical

description of simultaneous network setup/teardown events. In this manner, a realistic ensemble of event arrivals, and hence setup/teardown activities was obtained.

The scheduling simulation develops a minute by minute schedule of data dump and tracking support events compatible with spacecraft requirements identified in the mission model (see Appendix A). Before and after each data, track, or data and track event, variable network setup/teardown times were specified. A review of the schedule then allows for the accumulation of simultaneous setup/teardown event statistics.

Five 8-hour schedules for each of six setup/teardown time combinations were generated and analyzed for four system loading conditions. Setup times were chosen to be one, three, and five minutes, and teardown times one and three minutes. The five minute setup and three minute teardown times form the current estimate of the upper bounds for these activities. The remaining points were selected to obtain the desired data characteristics with minimum execution of the computer simulation. System loadings were 0.25, 0.50, 1.0, and 2.0 times baseline. These loadings were selected to be comparable with those used in the Phase I sensitivity analysis. The following statistics were compiled as a function of load and setup/teardown combination:

- (1) The average number of simultaneous events per minute,
- (2) The maximum number of simultaneous events developed,
- (3) The most frequent number of simultaneous events experienced, and
- (4) The frequency distribution of simultaneous events.

These data were analyzed for TDRSS MA, SA, and GSTDN events, and cast in a form similar to that in the lower portion of Figure 1-8-1.

D. PHASE III ANALYSIS RESULTS

1. Average Number of Simultaneous Events

a. Multiple Access (MA)

Figure 1-8-2 depicts the MA manpower requirement inter-

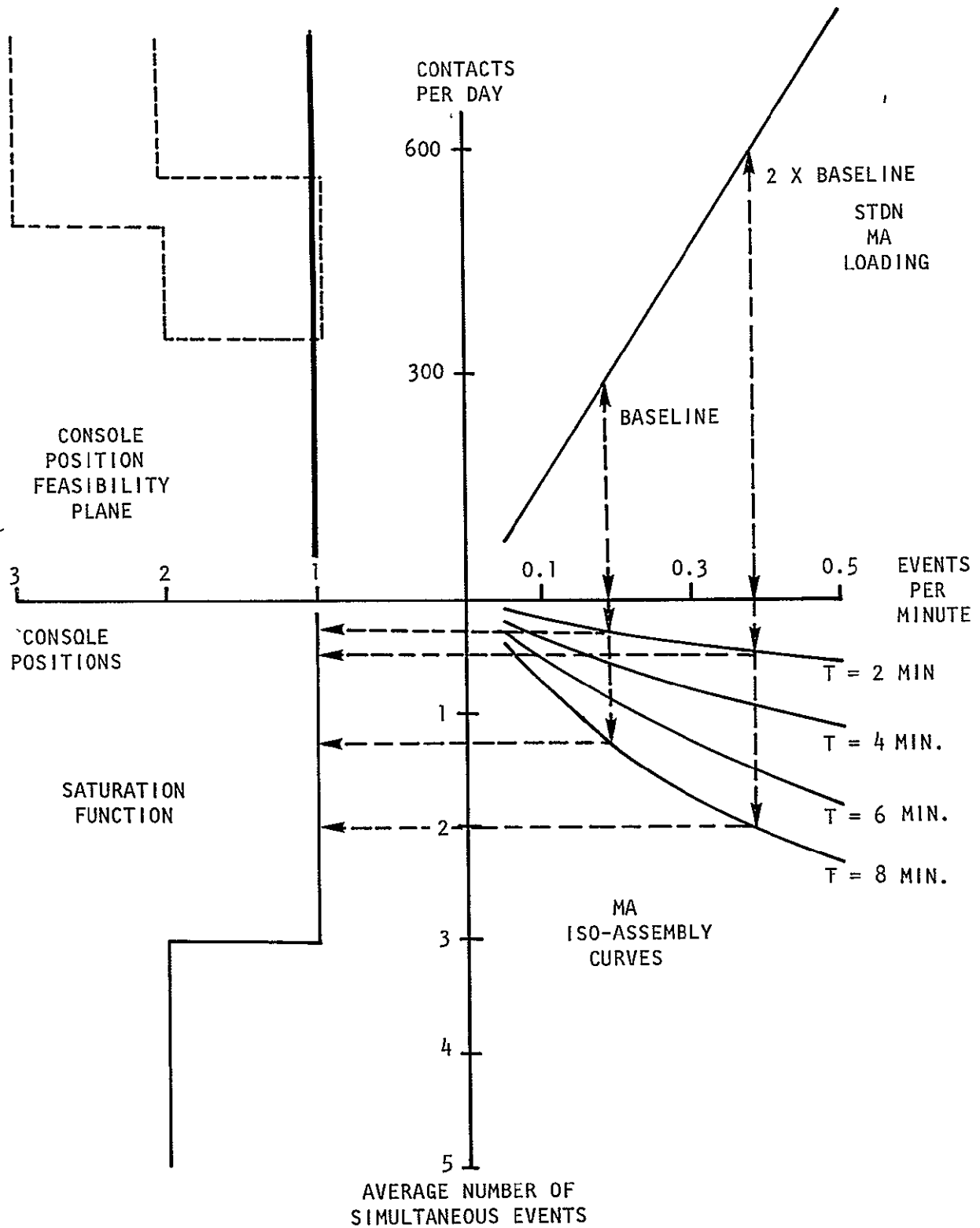


Figure I-8-2. MA Manpower Loading

dependencies. The iso-assembly curves in this and similar succeeding figures are parameterized in total control activity (setup plus teardown) time, T . Investigation of the data resulting from the parametric runs identified above indicated that the simultaneous events produced for setup/teardown times of 1 minute/3 minutes and 3 minutes/1 minute were not significantly different. This result was also observed for setup/teardown times of 3 minutes/3 minutes and 5 minutes/1 minute. Thus, four curves are shown which display the results of all parameteric runs. The correlation is as shown in Table 1-8-1. It should be remembered that the data obtained for cases 2 and 3, as well as 4 and 5, allowed the results to be displayed in 4 iso-assembly curves. It should not be assumed that these results are valid for all combinations of setup and teardown times which equate to $T=2, 4, 6$ or 8 minutes. The distinctive difference between Figures 1-8-2 and 1-8-1, aside from the simulated schedule loading reflected in Figure 1-8-2, is that the ordinate axis for quadrants two and three of Figure 1-8-2 is now the average number of simultaneous events. Thus, at twice the MA baseline loading (560 contacts per day), an operator setting up and tearing down for a combined time of eight minutes will experience an average of two simultaneous events per minute. Again assuming an individual operator saturation at three simultaneous events, it is apparent that only one operator is required to support MA loads of up to twice baseline load. For comparison with Phase II results, the fourth quadrant feasibility plane of Figure 1-8-1 is also included in Figure 1-8-2 (dotted line).

b. Single Access (SA)

SA manpower interdependencies are illustrated in Figure 1-8-3. Here, the average number of simultaneous events generated by baseline loading, assuming even the longest ($T=8$) setup/teardown time, is easily supported by one operator. However, loads up to twice baseline will require two operators.

If MA and SA manpower requirements are based on an average number of simultaneous events it must be recognized that an operator must have the capability to "hold" events on those occasions when the

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TABLE 1-8-1. CORRELATION OF PARAMETRIC RUN AND ISO-ASSEMBLY CURVES

CASE	SETUP TIME (MIN)	TEARDOWN TIME (MIN)	ISO-ASSEMBLY CURVE
1	1	1	T=2
2	1	3	T=4
3	3	1	T=4
4	3	3	T=6
5	5	1	T=6
6	5	3	T=8

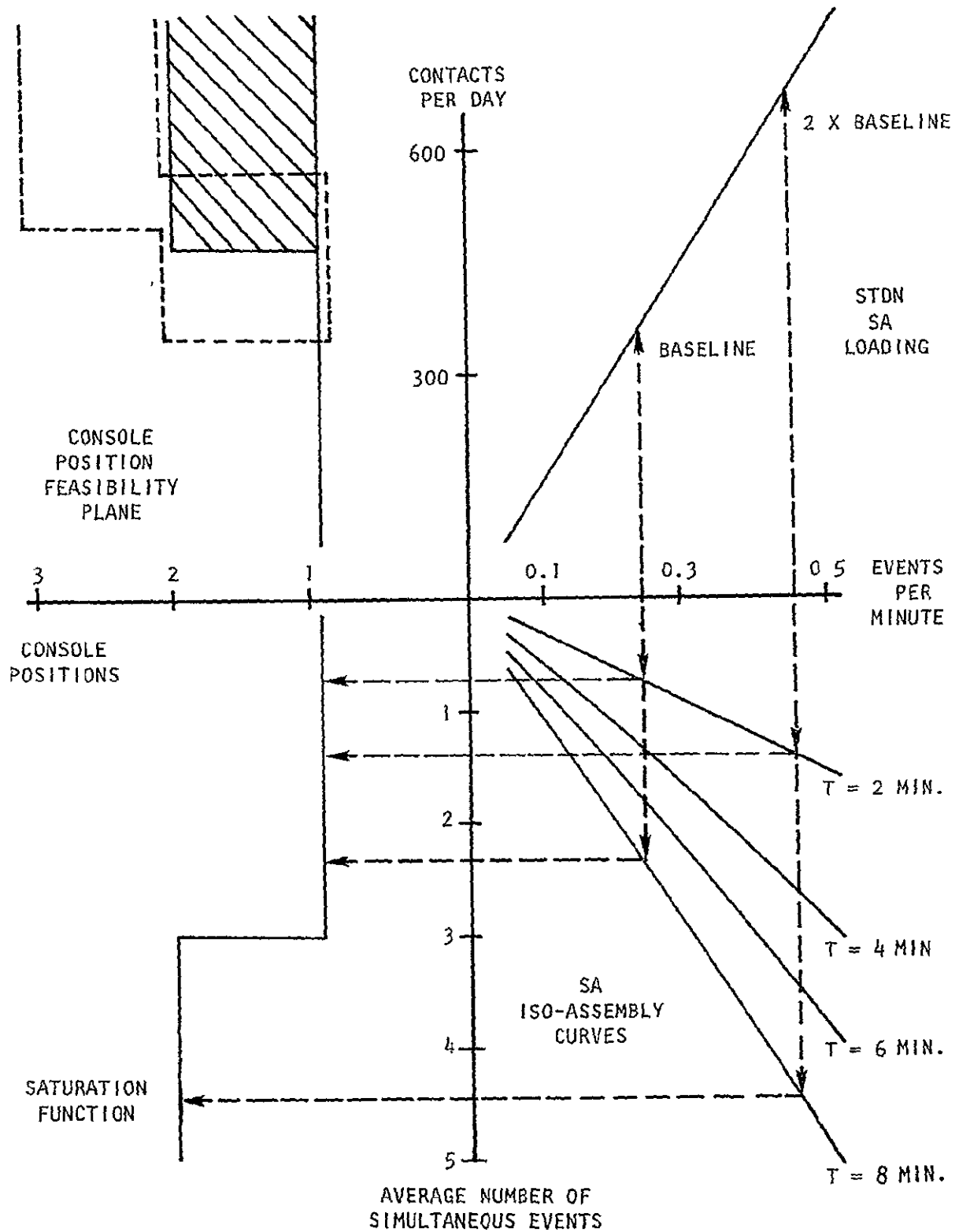


Figure 1-8-3. SA Manpower Loading

event rate exceeds his saturation function. Such "held" events are then disposed of in operator free time. If all events must be considered and acted upon in real time, however, manpower requirements are dictated by the maximum number of simultaneous events, as discussed below.

2. Maximum and Most Frequent Numbers of Simultaneous Events

Tables 1-8-2 and 1-8-3 summarize, for both MA and SA and for each assembly time and load, the maximum number of simultaneous events experienced as well as the number of operators required to provide immediate support for these events. Also tabulated are the most frequently occurring number of simultaneous events, the fraction of time they occur, and the fraction of operator free time. The scope of this analysis did not include an investigation of the optional method of allocating events to controllers. Therefore, in computing operator free time, if more than one controller is required at a position, it was assumed that each successive controller accepted only those events exceeding his predecessor's saturation level.

Consider, for example, the $T=6$ min. MA base line case displayed in Table 1-8-2. A maximum number of six simultaneous events occurred thus requiring two operators. As indicated in the table, the second operator, who accepts only those events exceeding the saturation level of the first, is idle approximately 98% of the time under the foregoing assumption. Also, the first operator will be either idle or analyzing only one event 73% of the time. Similar situations prevail throughout the MA baseline load case, as well as the SA baseline case. Thus, whereas two operators for both SA and MA are required for those instances of peak simultaneous events, their combined fraction of free time easily exceeds one-half. For a system loading of twice baseline, MA support requires between two and three positions and SA between three and four.

The frequency distributions of simultaneous events from which both operator free time and most frequent event statistics appearing in Tables 1-8-2 and 1-8-3 were compiled are illustrated in Figures 1-8-4 through 1-8-7. Included are distributions for baseline and twice base-

TABLE 1-8-2 MA SIMULTANEOUS EVENT CHARACTERISTICS

<u>LOADING</u>	<u>T (MIN.)</u>	<u>MAXIMUM NO. EVENTS</u>	<u>NO. REQ. OPERATORS</u>	<u>OPERATOR FREE TIME</u>			<u>MOST FREQUENT EVENT/FREQ.</u>
				<u>1</u>	<u>2</u>	<u>3</u>	
1/4 BASELINE	2	2	1	.92			0/.92
	4	3	1	.84			0/.84
	6	3	1	.76			0/.76
	8	3	1	.70			0/.70
1/2 BASELINE	4	3	1	.64			0/.64
	6	3	1	.47			0/.47
	8	4	2	.40	.99		0/.40
BASELINE	2	3	1	.71			0/.71
	4	5	2	.50	.99		0/.50
	6	6	2	.34	.98		1/.39
	8	6	2	.26	.91		1/.33
2 BASELINE	4	5	2	.30	.98		1/.38
	6	6	2	.18	.90		1/.30
	8	7	3	.11	.80	.99	2/.28

TABLE 1-8-3. SA SIMULTANEOUS EVENT CHARACTERISTICS

LOADING	T (MIN.)	MAXIMUM NO. EVENTS	NO. REQ. OPERATORS	OPERATOR FREE TIME				MOST FREQUENT EVENT/FREQ.
				1	2	3	4	
1/4 BASELINE	2	2	1	.83				0/.83
	4	3	1	.69				0/.69
	6	3	1	.58				0/.58
	8	3	1	.50				0/.50
1/2 BASELINE	4	3	1	.51				0/.51
	6	4	2	.35	.99			1/.41
	8	4	2	.24	.99			1/.41
BASELINE	2	5	2	.58	.99			0/.58
	4	5	2	.30	.97			1/.40
	6	6	2	.16	.93			1/.34
	8	6	2	.10	.79			2/.31
2 BASELINE	4	7	3	.07	.79	.99		2/.26
	6	9	3	.03	.58	.95		3/.22
	8	10	4	.01	.44	.86	.99	4/.22

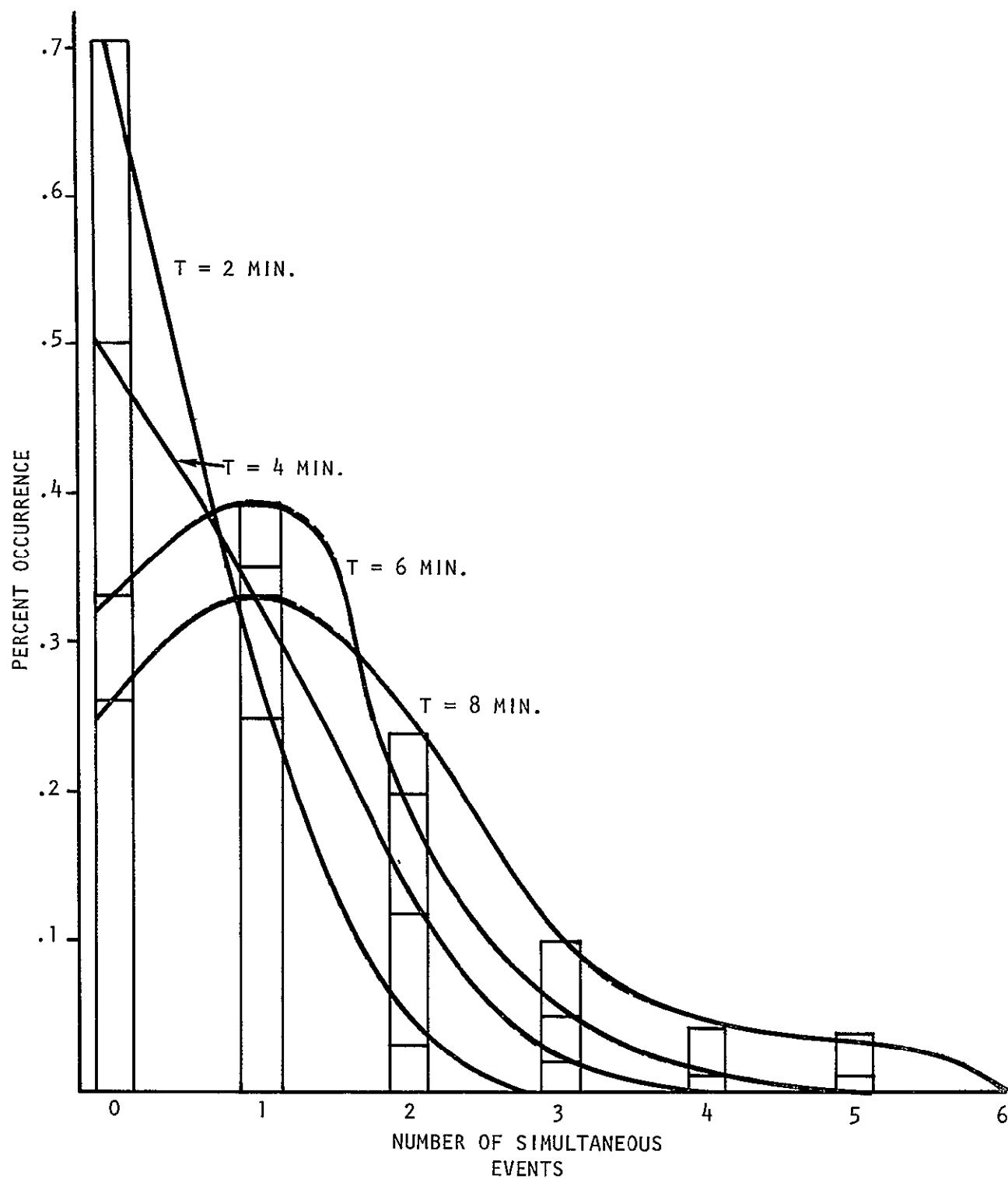


Figure I-8-4. MA Distribution of Simultaneous Events
Baseline Load

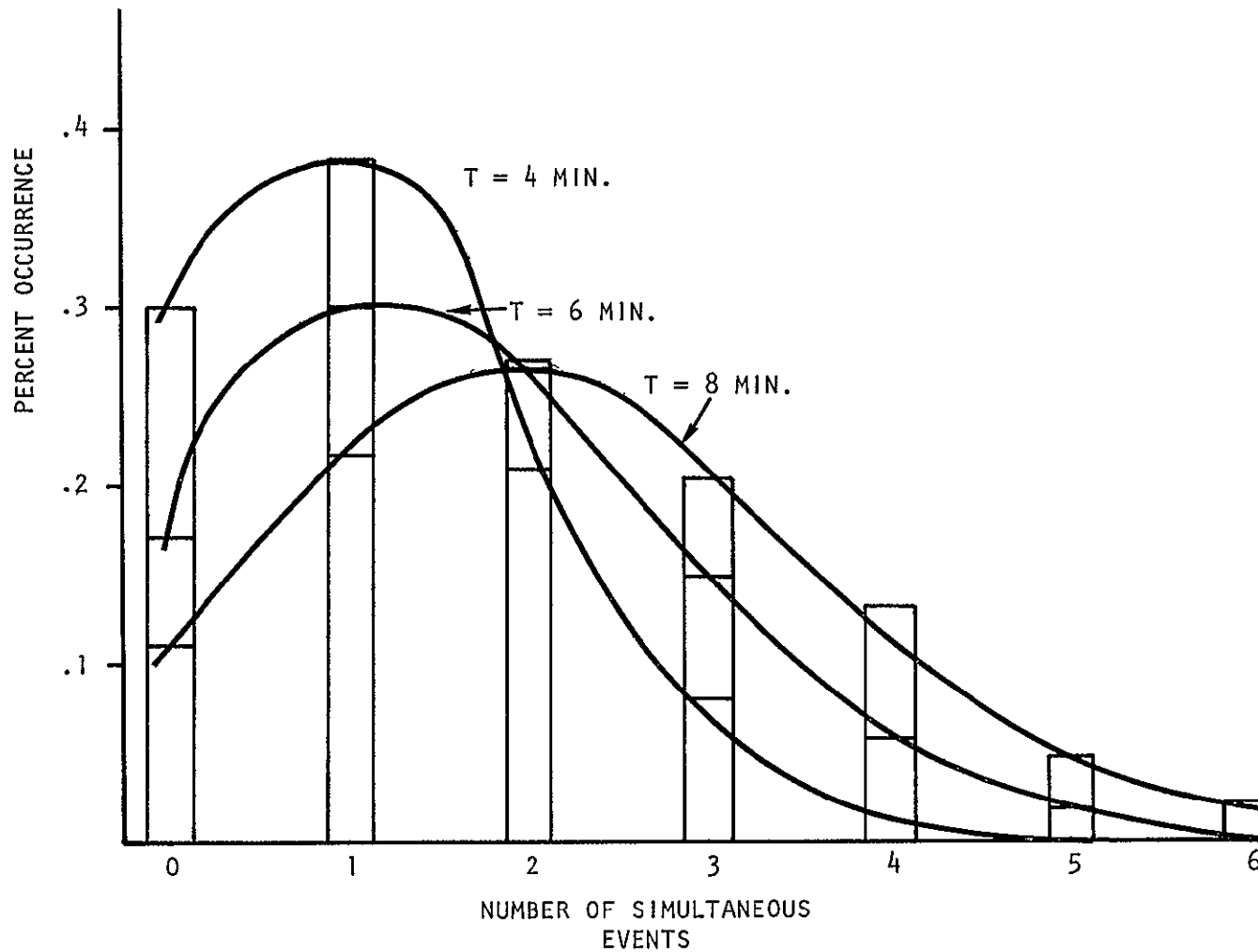


Figure 1-8-5. MA Distribution of Simultaneous Events
Twice Baseline Load

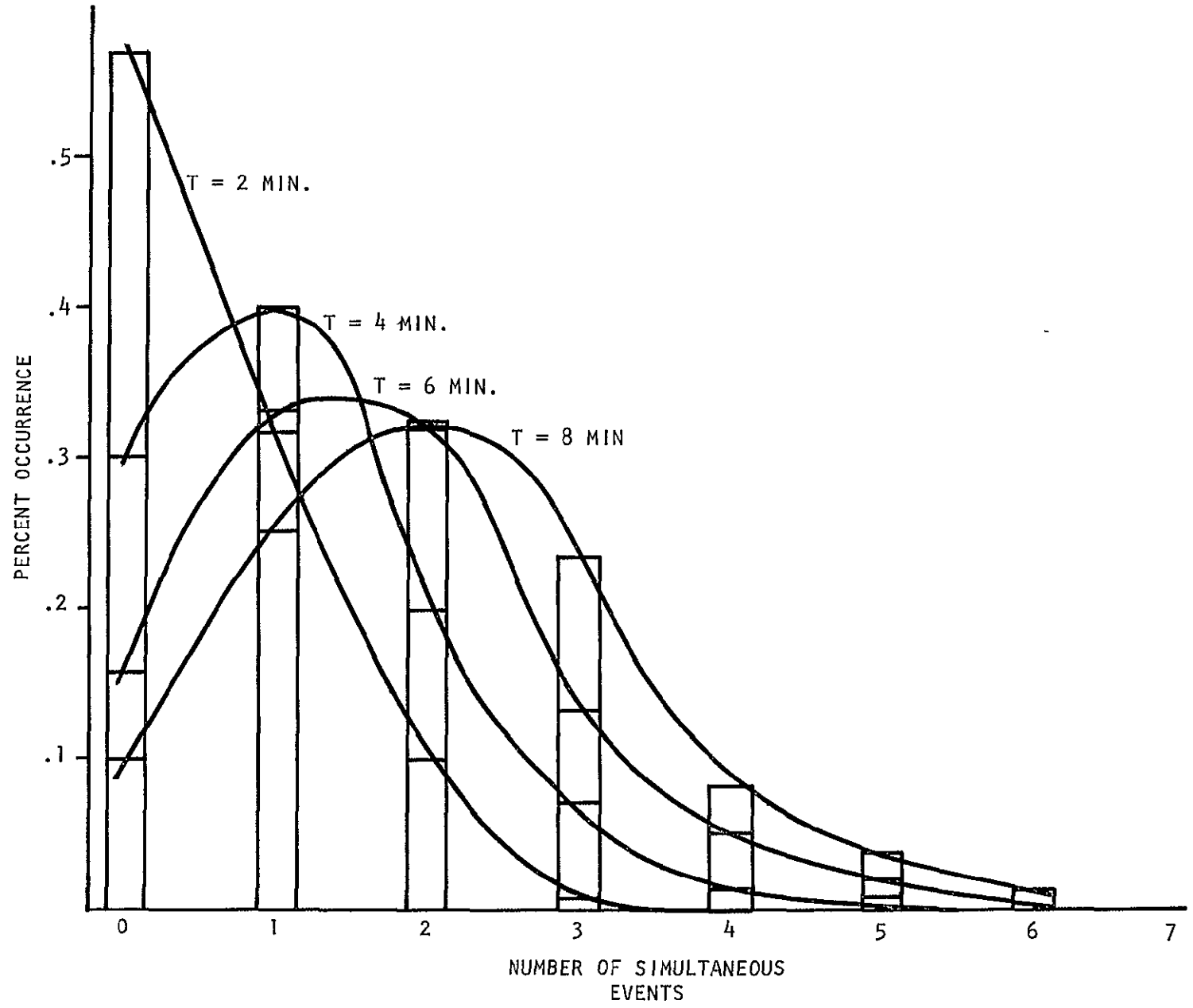


Figure 1-8-6. SA Distribution of Simultaneous Events
Baseline Load

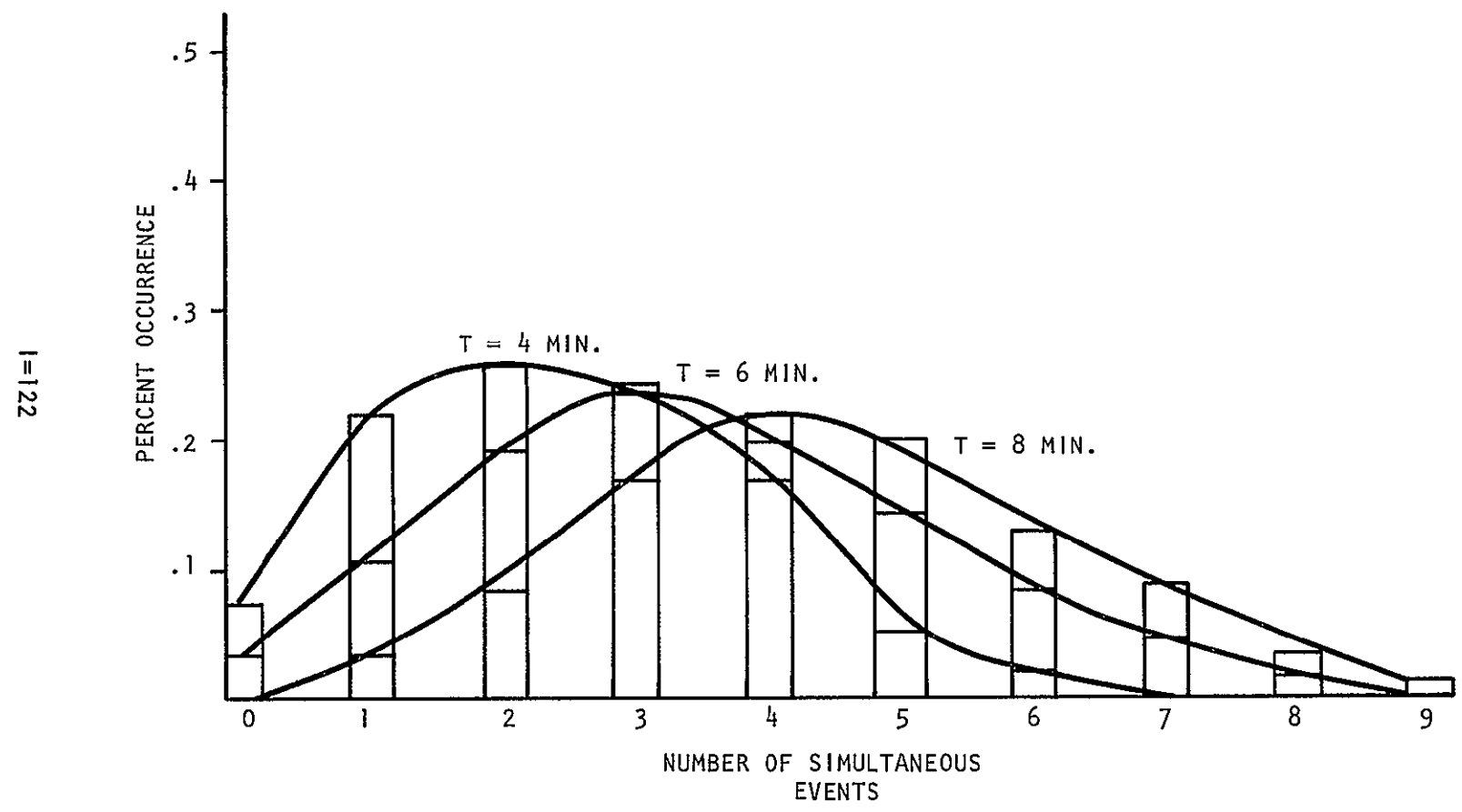


Figure 1-8-7. SA Distribution of Simultaneous Events
Twice Baseline Load

line for both MA and SA events. In order to distinguish the histogram-distributions for each of the four setup/teardown time combinations, plot "envelopes" have been sketched.

The general distribution shapes and deformations of shapes with varying setup/teardown times are as expected. Thus, in the MA base-line load case, Figure I-8-4, as setup/teardown times increase, the operator will have less and less free time (i.e., number of zero simultaneous events), whereas the number of maximum simultaneous events to be considered will increase.

3. TDRSS Manpower Requirements

Based on the average number of simultaneous events occurring during base line loading conditions, one MA operator and two SA operators are sufficient for TDRSS system support. This manpower requirement, however, assumes an operator ability to place events exceeding operator saturation into a "hold" queue.

In the case that simultaneous events are assumed to require immediate, real-time consideration, the maximum number of simultaneous events occurring is relevant and is found to demand two MA operators and two SA operators. Here, the combined idle time of either team of operators will generally exceed 50%.

E. PHASE III ANALYSIS RESULTS-GSTDN

1. Introduction and Approach

The number of GSTDN controller positions is a direct function of system load, network setup/teardown times, and operator efficiency. In order to obtain a description of GSTDN manpower requirements as well as insure adequate NCC support prior to, during, and following the planned ground station reconfiguration, a scheduling simulation similar to that adapted to the TDRSS analysis above, yet unique to GSTDN operations, was developed.

The computer simulation of GSTDN setup/teardown event generation

involves a random scheduling algorithm to approximate NCC user demand, and allows for segmenting required data and tracking dumps to account for the geographical constraints of actual ground stations. The system load employed in the simulation is given in Table 1-8-4, which illustrates the type of spacecraft supported as well as their associated support requirements. This loading reflects that of the first quarter of 1981 and as such, represents the heaviest GSTDN workload (Reference 42). The consequent identification of manpower requirements in this case is expected to represent an upper bound. It should be noted that it was assumed that the configuration of GSTDN in the 1981 period of interest could support the indicated loading. Thus the only dependent variable was the manpower required to manage the contacts.

For each of the six setup/teardown times (1/1), (1/3), (3/1), (3/3), (5/1), (5/3), ten schedules were generated and analyzed for their simultaneous setup/teardown event statistical characteristics. Note that in contrast with the TDRSS analysis, in which four system loadings were considered, only the heaviest expected GSTDN load is considered here. Table 1-8-5 summarizes the relevant parameters, and Figure 1-8-8 the frequency distribution of simultaneous events for each of the four distinct setup/teardown times. Again the combinations (1/3) and (3/1) yielded identical results, as did the combinations (3/3) and (5/1).

2. Discussion

From Table 1-8-5, the number of operators required to support the maximum number of simultaneous events ranges from two to three. As above, this assumes an individual operator can handle no more than three simultaneous events. In the two cases $T=6$ min. and $T=8$ min. in which three operators are required, the third operators are seen to be idle a large fraction of time. It is therefore estimated that setup/teardown combinations ranging from 2 to 8 min. can be essentially supported by two operators. In addition, based on the average number of simultaneous events, two operators (with a combined saturation of 6 events) can easily support GSTDN requirements.

TABLE 1-8-4. STDN LOADING CHARACTERISTICS

<u>SPACECRAFT</u>	<u>SUPPORT PER ORBIT (MIN.)</u>
LANDSAT-2	14
LANDSAT-C	20
NOAA-OS-A	4
SEASAT-A	6
HEAD-B	6
NIMBUS-G	10
ERS OS-A	3
SAGE AEM-B	7
NOAA-OS-B	4
HEAO-C	6
EE(UK)	10
EE-A	10
GRE	5
SMM	6
ATS-6	30
IUE	30
TDRS-A	30
TDRS-B	30
TDRS-C	30
ISEE-C	30

TABLE 1-8-5. GSTDN SIMULTANEOUS EVENT CHARACTERISTICS

<u>T (MIN)</u>	<u>AVG.NO.SIMULT. EVENTS/MIN.</u>	<u>MAXIMUM NO.EVENTS</u>	<u>NO.REQ. OPERATORS</u>	<u>OPERATOR FREE TIME</u>			<u>MOST FREQUENT EVENT/FREQ.</u>
				<u>1</u>	<u>2</u>	<u>3</u>	
2	0.93	4	2	.39	.99		0/.39
4	1.82	6	2	.15	.90		1/ .29
6	2.80	8	3	05	.71	99	2/.24
8	3.62	9	3	01	56	95	3/.23

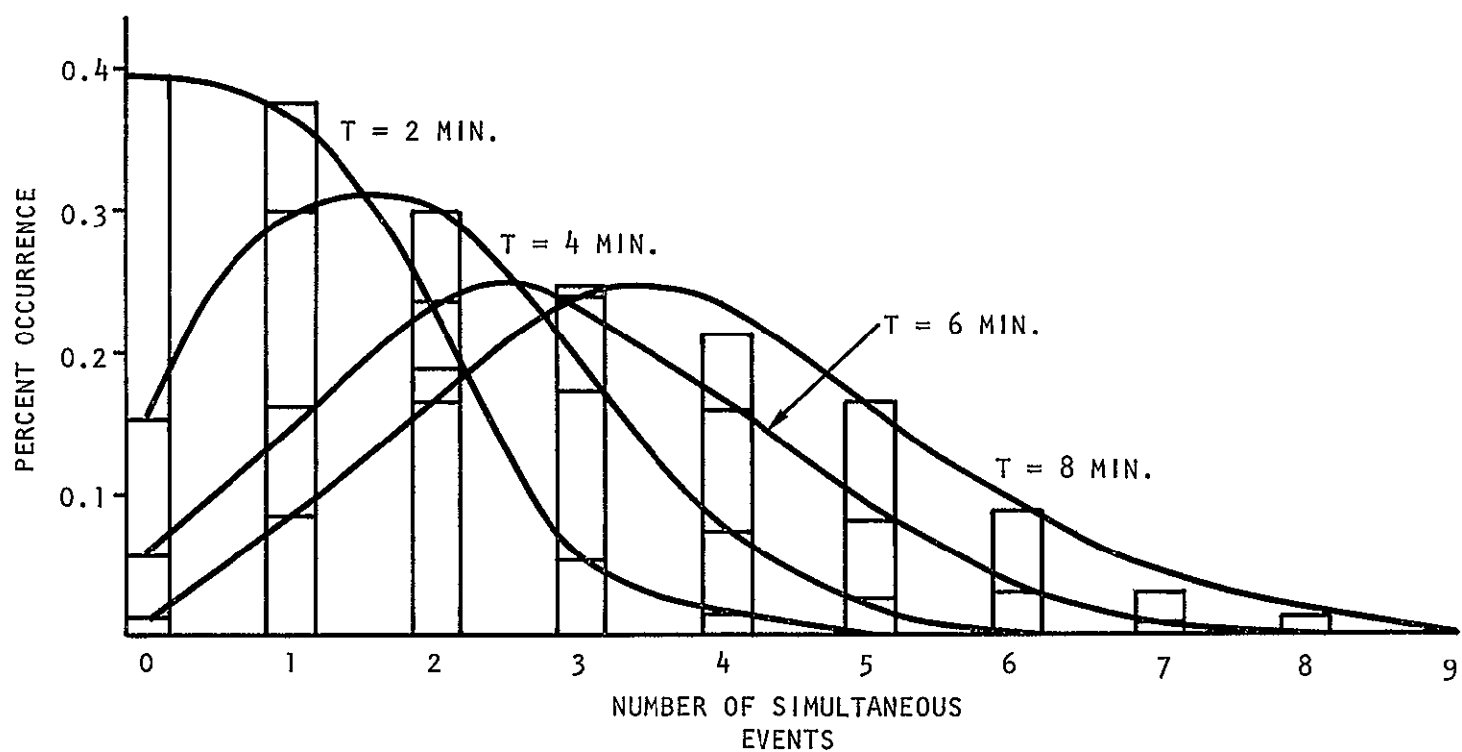


Figure 1-8-8 . GSTDN Distribution of Simultaneous Events

F MANPOWER REQUIREMENTS: SUMMARY

The extension of the Phase II manpower analysis in this study by the incorporation of simulated schedules has allowed for a more realistic generation of event arrival rates and an individual assessment of MA, SA, and GSTDN operator requirements. In addition, an accounting of both the average and maximum numbers of simultaneous events provides staffing decision flexibility in that operator saturations rated at either average or maximum numbers of events could be applied.

Table I-8-6 summarizes the load-dependent manpower requirements for the support of NCC MA, SA, and GSTDN network setup/teardown operations. The number of operators required based on two saturation functions are displayed: those which saturate at three average simultaneous events per minute, and those saturating at only three events, whenever they occur. Thus, for the expected baseline load, a maximum of two MA, two SA, and three GSTDN operators are required.

It should be noted that these manpower requirement results are very sensitive to the assumed individual operator saturation level. For example, if operators can be trained to consider up to six simultaneous events (which, in baseline load, occurs infrequently), only one MA and one SA position would be required. In addition, for those positions which are staffed, optimum scheduling of operator activity could maximize operator control and monitoring of system events.

TABLE I-8-6. MANPOWER REQUIREMENTS SUMMARY

<u>TDRSS</u>				
<u>LOAD</u>	<u>MA</u>		<u>SA</u>	
	<u>A*</u>	<u>M***</u>	<u>A</u>	<u>M</u>
1/4 BASELINE	1	1	1	1
1/2 BASELINE	1	2	1	2
BASELINE	1	2	1	2
2x BASELINE	1	3	2	4
<u>GSTDN****</u>				
		<u>A</u>	<u>M</u>	
		2	3	
<p>*A = Number of operators required based on the average number of simultaneous events per minute.</p> <p>**M = Number of operators required based on the maximum number of simultaneous events developed.</p> <p>*** Based on expected peak loading.</p>				